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Unmanned tactical autonomous control and collaboration coactive design

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MONTEREY, CALIFORNIA

THESIS

UNMANNED TACTICAL AUTONOMOUS CONTROL AND COLLABORATION COACTIVE DESIGN

by

Matthew S. Zach

June 2016

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Unmanned tactical autonomous control and collaboration (UTACC) is a Marine Corps experimental research initiative with the overarching aim of developing a collaborative human-robotic system of systems (SoS). This thesis analyzed the results of the existing UTACC concept development and incorporated them into an emergent human-robotic system development method, Coactive Design. An advantage to using this method is that it includes the human and his or her internal processes when modeling the system. As such, the focus is shifted to supplementing team capacities vice developing autonomy.

The two aims of this thesis are (1) to provide a recommendation for incorporating the Coactive Design method into the systems' development life cycle and (2) to provide a list of design requirements for a resilient UTACC SoS. Resilience is realized by designing for flexibility. A teamwork infrastructure built on many interdependent relationships provides this flexibility. These interdependent relationships can be grouped into three areas: observability, predictability, and directability. Counter to conventional practices within the robotics industry, Coactive Design focuses on managing these interdependencies rather than focusing on autonomy. Coactive Design also provides a cost-benefit analysis of development choices, which assists with developing efficiencies during the design and development of the system.

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UNMANNED TACTICAL AUTONOMOUS CONTROL AND COLLABORATION COACTIVE DESIGN

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ABSTRACT

Unmanned tactical autonomous control and collaboration (UTACC) is a Marine Corps experimental research initiative with the overarching aim of developing a collaborative human-robotic system of systems (SoS). This thesis analyzed the results of the existing UTACC concept development and incorporated them into an emergent human-robotic system development method, Coactive Design. An advantage to using this method is that it includes the human and his or her internal processes when modeling the system. As such, the focus is shifted to supplementing team capacities vice developing autonomy.

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LIST OF ACRONYMS AND ABBREVIATIONS

5PO	Five Paragraph Order
5Ws	who, what, where, when, why
AA	avenue of approach
BAMCIS	begin planning, arrange reconnaissance, make reconnaissance, complete the plan, issue the order, supervise activities
BP	battle position
C2	command and control
C4I	command, control, communications, computers, and intelligence
CMU	communications management unit
COA	course of action
COMSEC	communications security
CONOPS	concept of operations
COP	combat operational picture
DARPA	Defense Advanced Research Project’s Agency
DDSP	degraded sensor posture
DIACAP	DOD’s Information Assurance Certification and Accreditation Process
DOD	Department of Defense
DRC	DARPA Robotics Challenge
DSP	defensive sensor posture
DRAW-D	defend, reinforce, attack, withdraw, delay
EF21	Expeditionary Force 21
EM	electromagnetic
EMDCOA	enemy’s most dangerous course of action
EMLCOA	enemy’s most likely course of action
FCC	Federal Communications Commission
FSP	fire support plan
FMC	fully mission capable
HHQ	higher headquarters
H-M	human-machine

IA	Interdependence Analysis
IED	improvised explosive device
IERs	information exchange requirements
IHMC	Institute of Human Machine Cognition
IP	initial point
IR	infrared
ISR	intelligence, surveillance, and reconnaissance
LZ	landing zone
MCCD	Marine Corps Combat Development Command
MCDP	Marine Corps Doctrinal Publications
MCOO	Modified Combined Obstacle Overlay
MCRP	Marine Corps Reference Publication
MCWP	Marine Corps Warfighting Publications
MCWL	Marine Corps Warfighting Laboratory
MGRS	military grid reference system
MOE	measure of effectiveness
MOP	measure of performance
NASA	National Aeronautics and Space Administration
NFA	no fly area
NIST	National Institute of Standards and Technology
NMC	non-mission capable
NPS	Naval Postgraduate School
NSP	neutral sensor posture
OCONUS	outside the continental United States
OODA	observe, orient, decide, act
OPD	observability, predictability, directability
ORP	objective rally point
OSMEAC	orientation, situation, mission, execution, administration and logistics, command and signal
OSP	offensive sensor posture
PIR	priority information requirement
PMC	partially mission capable

RFID	radio-frequency identification
RMF	risk management framework
RTB	return to base
SALUTE	size, activity, location, unit, time, equipment
SOM	scheme of maneuver
SoS	system of systems
SOW	statement of work
TAW	Task Analysis Worksheet
UAV	unmanned air vehicle
UAS	unmanned air system
UGV	unmanned ground vehicle
UGS	unmanned ground system
USMC	United States Marine Corps
UTACC	Unmanned Tactical Control and Collaboration
UxS	unmanned system in general
UxV	unmanned vehicle in general
VLANS	virtual local area networks
VRC	Virtual Robotics Challenge

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EXECUTIVE SUMMARY

This thesis is part of an ongoing initiative to support the Unmanned Tactical Autonomous Control and Collaboration (UTACC) effort sponsored by the Marine Corps Warfighting Laboratory (MCWL). UTACC is being designed as a system of systems (SoS) that includes autonomous air and ground components geared to provide intelligence, surveillance, and reconnaissance (ISR) for support of Marine Corps tactical units. What separates UTACC from other such systems is the collaborative nature of the interdependent human-machine (H-M) team. The UTACC system is being developed through an iterative and incremental design process as a means of satisfying the need for exploratory, technological research called for in the Marine Corps' current, strategic and visionary planning document, Expeditionary Force 21.

UTACC completed its initial concept development in 2015 and immediately set about defining requirements to support those concepts. The search for a methodology that could assist with accurately capturing these requirements and relationships that support them became a critical investment and one of the aims of this thesis. The Coactive Design method was chosen for analysis of any potential UTACC suitability due to the acclaim for the method's architect, Dr. Matthew Johnson, from the 2013 Defense Advanced Research Projects Agency's (DARPA) Virtual Robotics Challenge (VRC) and the 2015 DARPA Robotics Challenge (DRC). Coactive Design is an emergent H-M design method that helps decipher high-level teaming concepts into reusable and programmable controls, interface components, and behaviors that allow machines to act as teammates.

Coactive Design is based on the concept of interdependence among humans and machines operating as a team in order to accomplish a mission. These coactively designed interdependencies are broken down into three categories: observability, predictability, and directability. This interdependence framework runs counter to the conventional H-M system design wisdom, which seeks to increase levels of system autonomy or human independent actions. The Interdependence Analysis (IA) Tables are the tool that Coactive Design uses to generate system requirements. The tables decompose tasks into the most elemental capacities required in order for these tasks to be performed. After task decomposition, each individual capacity is studied within the context of the H-M relationships and requirements are then derived that help support those relationships.

This thesis's research has had several impact areas on the UTACC initiative. First, Coactive Design provides UTACC a list of detailed system design requirements. Second, Coactive Design offers UTACC a means of achieving a resilient system by designing alternate pathways for recognizing and managing uncertainty. These pathways were realized as a result of the analysis conducted using the IA Tables, and provide the H-M team flexibility in the way the team approaches the tasks and how the team adapts to problems in tactical situations. Third, this thesis provides recommendations on which capacities UTACC should focus on, given its limited developmental time and resources. As was the case with the system flexibility provided through alternative teaming pathways, the design and development efficiencies are also a direct byproduct of the IA Table analysis. Lastly, the UTACC specific Coactive Design has the added benefit of fusing and preserving several preceding UTACC efforts. For these reasons, the author recommends incorporating Coactive Design into the entire development life cycle for UTACC, and suggests that this design method be considered for all of the Marine Corps' future H-M system development projects.

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My study of the Coactive Design Method has given me an appreciation of the interdependencies that exist among the members of a team. As such, I would be remiss for failing to acknowledge the interdependencies of my research team and how they led to my success in this academic endeavor. I feel indebted to many people, without whom my research and writing pursuits would certainly have been much more stressed. For their encouragement, assistance, and mentoring, I remain most grateful.

I begin by thanking Dr. Dan Boger and Scot Miller for taking me on as a thesis student. You provided clear direction, sufficient background, and the freedom and encouragement that allowed me to make decisions and excel in this endeavor. Next, I must thank Dr. Matt Johnson and the Florida Institute of Human and Machine Cognition (IHMC) for hosting me on two separate site visits, educating me on Coactive Design, and helping me to refine the Coactive Design of the Unmanned Tactical Autonomous Control and Collaboration (UTACC) system. I offer my sincere appreciation to Dr. Johnson, specifically. Your insights and willingness to share your work had significant impact on my writing. Third, I must thank Majors Thomas Rice, Erik Keim, and Tom Chhabra for their willingness to teach me about their work on the UTACC Concept of Operations. They were also the ones that first introduced me to UTACC, and without whom I would not have been a part of this promising exploratory initiative. Last but not least, I must thank my family: Stephanie, Henry, Cheryl, Janelle, and Tony. I love you all and cannot thank you enough for your patience and belief in me, as well as for your support and encouragement throughout the entire process.

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I. INTRODUCTION

This thesis is part of an ongoing initiative to support the Unmanned Tactical Control and Collaboration (UTACC) effort sponsored by the Marine Corps Warfighting Laboratory (MCWL). The UTACC system is being developed through an iterative and incremental design process. As such, similarities exist between this work and that conducted both previously and in parallel. This thesis expands and utilizes many of the results and products developed under previous Naval Postgraduate School UTACC theses. The results of these authors' works were used to develop concurrent work for other such theses.

A. SPONSORING COMMAND, OBJECTIVE, AND RESULTS

MCWL is the parent command for the experimental UTACC initiative. The UTACC system is being designed as a system of systems (SoS) that includes autonomous air and ground components geared to provide intelligence, surveillance, and reconnaissance (ISR) for support of Marine Corps tactical units. The intent behind this thesis is to develop requirements for the interface that allows the human component of the UTACC team to communicate with the robotic elements and vice versa. These requirements will offer the system's engineers vital Marine Corps user perspective that will aid in the speed and ease of adopting the system at the user level. In their book, *Switch*, Chip and Dan Heath discussed organizational change to stress the importance of why soliciting and building user preferences from the beginning of the design and development phase is important for enterprise-level adoption during transformational change periods (2010).

The author has operational experience with Marine Corps unmanned aerial and ground systems; however, the author is not familiar with the UTACC proposed level of autonomy and collaborative capabilities. This operational experience will serve as an initial litmus test for use case development and will also provide user perspective, a key ingredient for interface design. These interface design requirements will be derived from Marine Corps tactics, techniques, and procedures, as well as, Marine Corps doctrinal and warfighting publications in order to ensure continued relevancy to the Marine Corps in the future.

B. RETURN ON INVESTMENT TO MARINE CORPS WARFIGHTING LAB

As technology continues to rapidly advance, the UTACC system offers the Marine Corps the opportunity to expand its capabilities, controlling the pace with which advanced autonomous robotics are incorporated into warfare. The coactive design methodology and tools are invaluable to UTACC's design process. Coactive design helps decipher high level teaming concepts into reusable and programmable controls, interface components, and behaviors that allow machines to act as teammates (Johnson, 2014). Within the UTACC construct, the defining of the interdependent relationships between human and machines provides MCWL with another critical payoff. This paradigm shift from dependent to interdependent relationships, along with an in-depth understanding of what interdependence means, comprises a revolution within the robotic design and development disciplines. Those who use this concept as the crux of their design framework are rewarded with an empirical competitive advantage in the form of increased observability, predictability, and directability between Marines and unmanned components.

C. RESEARCH METHODOLOGY OVERVIEW

As a small portion of the UTACC initiative, this thesis utilizes concepts from command, control, communications, computers, and intelligence (C4I) literature for building the requirements of the UTACC system. The requirements are built from the concept design conducted in Rice's, Keim's, and Chhabra's (2015) UTACC thesis work. The core of the Rice et al.'s (2015) work came in the form of MCWL-approved task analysis worksheets. These worksheets built upon the Marine Corps Troop Leading Steps, BAMCIS: begin the planning, arrange for reconnaissance, make reconnaissance, complete the plan, issue the order, and supervise (USMC, 2002). All Marines are taught this planning process during their basic training, and it serves as a fundamental building block within the Marine Corps user perspective. This thesis aims to provide the system designers and engineers such a perspective.

The task analysis worksheets were studied by the author and morphed into a more easily digestible form by the interdependence analysis (IA) tables, derived from those found in Johnson's (2014) doctoral thesis on Coactive Design. IA tables break down complex tasks into their most elemental sub-tasks and further to capacities required to complete the job. Once all of the worksheets were imported into the IA tables, the author refined and filled in gaps that were not identified by the Rice et al. (2015) team but were essential to the accomplishment of the overarching tasks they proposed. Then, each individual capacity was analyzed against all viable teaming role alternatives (e.g., robot or human) to see which was more capable of filling the requirement and to what extent the other teammates were able to assist. In this way, the interdependent relationships of the teammates were mapped out. The author then extrapolated requirements for the system-Marine interfaces that will serve to enable these interdependent relationships.

D. RELATED WORK

This thesis complements other theses conducted in the UTACC program. Rice, Keim, and Chhabra (2015) and Batson and Wimmer (2015) were the predecessors of this thesis work and formed the foundation of this thesis. The work of Kirkpatrick and Rushing is in progress at the time of this writing and focuses on mapping the requirements also identified in this thesis to measures of performance (MOPs) and measures of effectiveness (MOEs). The work of Larreur is also in progress and focuses on establishing a roadmap of experimentation to validate the requirements of this thesis and evaluate the MOPs and MOEs suggested in Kirkpatrick's and Rushing's work.

Johnson's (2014) work and preceding publications on interdependence, autonomy, and especially Coactive Design were of critical importance to this thesis. Johnson (2014) developed the Coactive Design model and interdependence analysis tables for use within a single human-single machine teaming environment that this author modified to the many humans-many machines environment unique to UTACC.

E. NEED FOR COACTIVE DESIGN WITHIN UTACC

Coactive Design offers MCWL a methodical, efficient, and user centric iterative process for building UTACC. It is a method for designing interdependent systems that uses a design tool called an interdependence analysis table, which details human-machine requirements. The requirements guide implementation of the system, providing teamwork infrastructure. The accumulation of all the capabilities under the teamwork infrastructure determines the runtime options, which determine performance (Johnson, 2014). The flexibility provided by these options will equate to a vastly resilient UTACC system.

F. CHAPTER SUMMARY

This chapter has provided a broad overview of UTACC and described why the program is necessary within the backdrop of the Marine Corps' Expeditionary Force 21 (EF21). As a result of this necessity, MCWL, as the sponsoring unit for this program, serves to benefit by continuing to invest with UTACC. MCWL's ROI will see improvements in both time to market and user acceptance if Coactive Design is adopted into the development life cycle of this program. Furthermore, this thesis offers the dual benefit of preserving the previous UTACC research efforts and in guiding parallel efforts. The most important product from this thesis is the list of system and user interface requirements, which were derived from the Coactive Design research methodology.

This UTACC specific Coactive Design merges several preceding works. The most influential of those efforts being the work of Johnson (2014), a revolution within human-machine teaming, and that of Rice et al. (2015), the UTACC concept development team. The next chapter explores these works in greater detail.

II. LITERATURE REVIEW

A. UNMANNED TACTICAL CONTROL AND COLLABORATION

Unmanned Tactical Control and Collaboration (UTACC) is a developing research effort concerned with human and machine teaming within the backdrop of the United States Marine Corps. The tactical application of UTACC is of interest to the Marine Corps Warfighting Laboratory (MCWL) as it explores the stated need for innovative and exploratory technological research called for in Expeditionary Force 21 (EF21). EF21 (2014) serves as the Marine Corps' current strategic and visionary planning tool that will help shape the force of the future. The Marine Corps Combat Development Command (MCCDC) recognizes that many of the initiatives with potential value offerings are not fully mature yet (MCCDC, 2014). However, MCCDC (2014) requires deliverables that aid in the development of future force capabilities. The UTACC coactive design products within this paper and paralleling, complementary research, if certified by MCWL, qualify for these future force capability shaping deliverables.

Military technology advances in the unmanned systems arena provide new capabilities while outsourcing current human performed tasks. This next generation of warfare research is aimed at lessening the cognitive load of humans as the interactions between humans and machines become more complex. To this end, Rice, Keim, and Chhabra (2015) identified the user interface as one of the most significant pieces of the UTACC system, as it bridges the gap between constantly evolving robotic agents and the humans that they must work with. This thesis further develops such previous UTACC research efforts. It proposes interface and systems design requirements that aim to bring these UTACC concepts to life. The design requirements are the direct result of the application of the coactive design method. Johnson's (2014) doctoral thesis proposed the coactive design process as a new approach to dissecting the nuanced interdependencies between humans and machines engaged in joint activity. This design process makes it possible for high-level concepts like collaboration and teamwork to be translated into requirements implementable through algorithms and programming behavioral logic.

B. UTACC VISION AND OVERVIEW

MCWL signed a FY14 statement of work (SOW) that proposed tasks for UTACC to conduct over the following three years; the end state being the production of a "decision-centric, semi-autonomous, distributive, multi-agent, multi-domain robotic system" (Statement of Work [SOW], 2014, p. 1). In order to accomplish this, UTACC leverages collaborative autonomy to significantly reduce operator interaction with robotic systems while not limiting the system's ability, thus improving human performance and promoting mission success. Under the SOW (2014), the UTACC system encompasses both semi-autonomous unmanned ground and air vehicles in addition to the human element.

Developed with a modular system of systems (SoS) approach, UTACC is designed to be scalable and adapt over time to encompass additional missions, adapt to new conditions, and rise to evolving threats (SOW, 2014). A reconnaissance mission was chosen as the initial frame of reference for building out the initial UTACC concept development. Within this single Marine Corps mission a small tactical team of four Marines, commonly referred to as a fire team, would serve as the human element within the greater UTACC construct (Rice et al., 2015).

C. EXPEDITIONARY FORCE 21

Published in March 2014, EF21 serves as the Marine Corps' new capstone concept, having replaced the Marine Corps Vision and Strategy 2025. It promotes plans, aligns future concepts and creates capability roadmaps (EF21, 2014). Part of the modern force attributes described within EF21 (2014) is the ability to exploit innovative concepts and methods allowing the Marine Corps to maintain its decisive edge over adversaries. UTACC offers to sharpen that edge through increased fidelity in planning coupled with the reduction in workload for the human operators during critical periods of the mission. Furthermore, UTACC seeks to leverage the Marine Corps traditional operating practices while building this SoS, with the users in mind from the very inception.

Marine Corps Warfighting and Doctrinal Publications (MCWPs and MCDPs) reinforce the concept and interface design processes. Gathering requirements from

Marine Corps missions, strategic vision, and publications allows for ease of integration and employment of the system of systems (SoS). This development method is initially more time intensive than adopting civil technologies within similar enterprises (Bernard, 2012). However, it does offer a more effective implementation plan than incorporating the requirements at the end of development (Bernard, 2012).

EF21 (2014) called for the Marine Corps to relentlessly pursue its return on investment across the enterprise while seeking these innovative approaches to capability development. The results of this thesis achieve this for UTACC; the main outputs provide system designers with tailored requirements for the system interface. It has also allowed other complementary research to continue in parallel, such as research supporting measures of performance and measures of effectiveness (MOPs and MOEs). The forward deployed posture that EF21 envisions projects one-third of the operating forces aboard. The final UTACC SoS offers the potential to redefine the Marine Corps enterprise. These could be realized in reductions to manning and the task organization of infantry battalions and company landing teams, the Marine Corps' standard deployment unit capable of securing landing sites or maneuvering to deep inland objectives during entry operations (EF21, 2014). These discussions will serve as areas requiring future research.

D. UTACC CONCEPT OF OPERATIONS

UTACC Concept of Operations, or concept design, was the thesis work of Rice, Keim, and Chhabra (2015), which set the stage for all follow on work within UTACC. It fits within the systems analysis and design process described by Satzinger, Jackson, and Burd (2012), which is where this thesis continues. Specifically, Rice et al.'s (2015) research captured the system requirements, logical sequencing of operational activities, and developed a model for mission planning and execution. Without these three functional areas, the UTACC coactive design model would not have been possible. A summary of these functional areas follows.

1. UTACC System Requirements

The SOW (2014) provides MCWL's endorsement of Rice et al.'s (2015) constraints for the final system's capabilities. They are summarized as:

- Adaptive behaviors providing reduced operator workload
- Collaborative command and control
- Distributive and modular architectural infrastructure
- Distributive processing and storage
- Organic mapping and obstacle avoidance
- Autonomous system diagnostics
- Ease of maintenance
- Organic power operation (SOW, 2014, pg. 2)

Reducing the current workload of the humans in the team is central to the fundamental purpose of UTACC. Tangent to this constraint is the ability of all components to collaborate their individual sensing and collecting capabilities. An integrated system interface provides the means to communicate this information back and forth between human and robot. Distributing functionality and making components modular allows the system to continue the mission should a single component be removed from the task. The UTACC system must be able to map its surroundings and avoid obstacles as it moves throughout the battlespace while collecting and sensing. Each system element must monitor its sensors' health, communication links to the team, and fuel status. Due to the expeditionary nature of these small tactical teams, the elements must be durable, allow for basic field maintenance, and must operate under their own power.

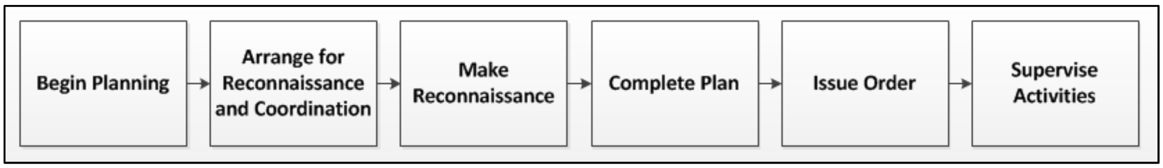
2. Sequence of Operational Activities

Rice et al. (2015) adapted the Marine Corps' troop-leading steps: begin planning; arrange for reconnaissance; make reconnaissance; complete the plan; issue the order; and supervise activities (BAMCIS) as the groundwork for building the functional UTACC model. These steps are important to the UTACC coactive design process because they serve as the highest level of organization within the UTACC coactive design model. The following quote from the *Marine Rifle Squad* (USMC, 2002) publication defines BAMCIS as:

> The troop-leading procedures listed below are aids in preparing for and executing assigned missions. They assist squad and fire team leaders in making the best use of time, facilities, and personnel. All the steps should be considered, but depending upon the mission and time available, the degree of consideration for each will vary.
>
> Begin Planning. When an order is received, the squad leader considers the time available to him. In so doing, he uses a planning sequence called reverse planning, meaning that he starts with the last action for which a time is specified (e.g., an attack) and works backward to the issuing of his order. This helps ensure that enough time is allowed for the completion of all necessary actions. During this stage, he also analyzes the terrain and the friendly and enemy situation. From his analysis, he formulates a preliminary plan of action to accomplish the mission. This plan is only tentative and will often be changed.
>
> Arrange for Reconnaissance and Coordination. The squad leader selects a route and prepares a schedule for reconnaissance and coordination with adjacent and supporting units. Normally, he takes his fire team leaders and the leaders of any attached crew-served weapons teams with him on his reconnaissance.
>
> Make Reconnaissance. On his reconnaissance, the squad leader completes his estimate of the situation. Prearranged meetings with adjacent squads and supporting units are held as scheduled. He notes how the terrain affects his preliminary plan and adopts, alters, or ejects it as necessary. While on his reconnaissance, he selects advantage point from which to orient his fire team leaders.
>
> Complete Plan. Upon his return from the reconnaissance, the squad leader completes his plan of action. He then prepares notes to be used in issuing his order.
>
> Issue Order. If possible, the squad leader issues his order to the same personnel he took with him on his reconnaissance from the vantage point he had selected earlier. If this is not possible, the team leaders are oriented from maps, sketches, or an improvised terrain model. He issues his order using the five-paragraph order sequence and includes everything his fire team and attached weapons leaders need to know.
>
> Supervise Activities. The squad leader continuously supervises his unit to ensure that his order is carried out as intended. (2002, pp. C1-C2)

These steps form a logical sequence of iterative events that allow Marines to conduct all pre-mission activities while ensuring a high likelihood of success during the execution phase. The BAMCIS process is uniquely suited for implementation as the backbone of the UTACC concept of operations due to the close familiarity that all Marines have with it. Figure 1 is a graphical depiction of these concepts.

Figure 1. Marine Corps Troop-Leading Steps (BAMCIS)

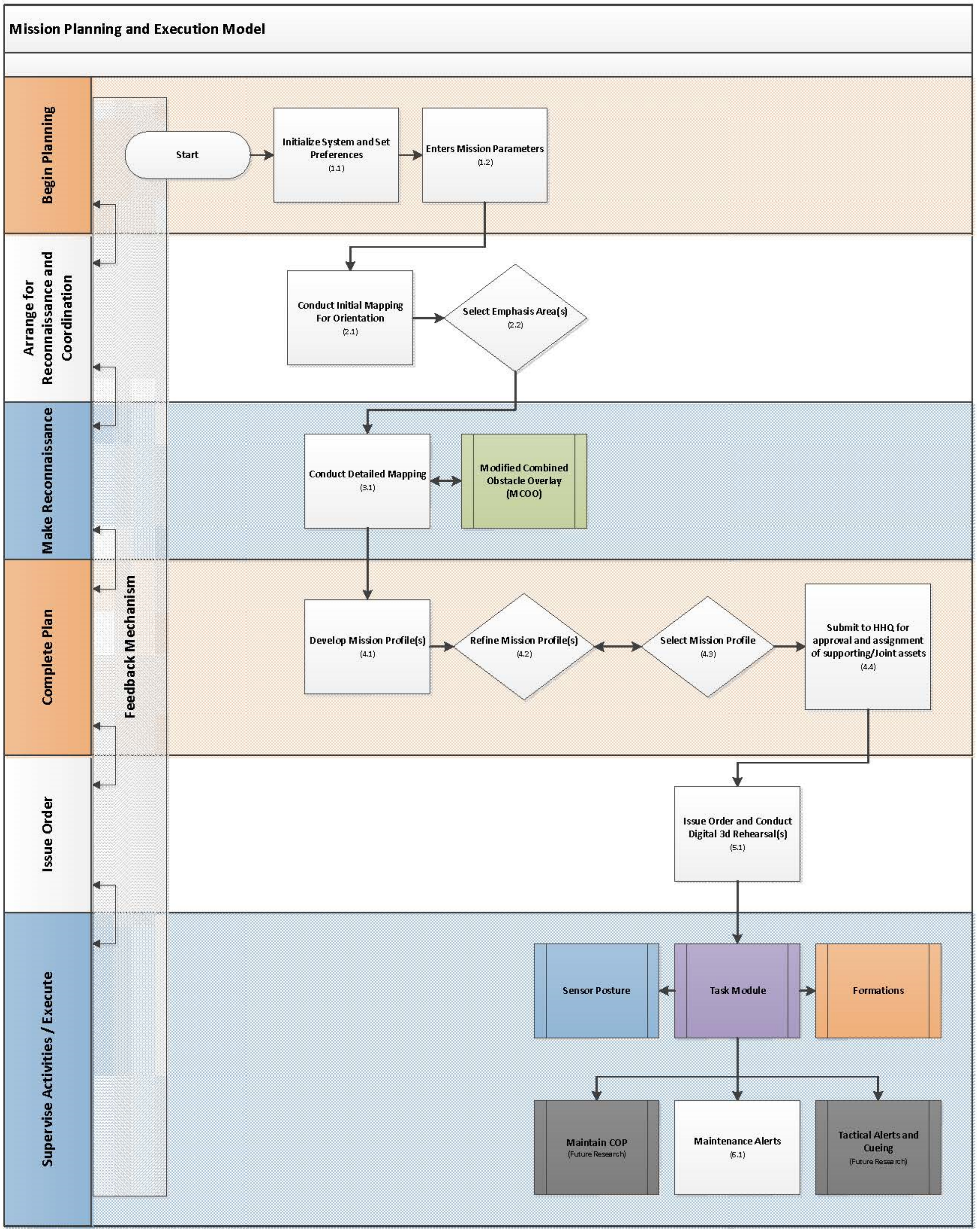


Source: Rice, T., Keim, E. A., Chhabra, T. (2015). *Unmanned tactical autonomous control and collaboration concept of operations.* (Master's thesis). Naval Postgraduate School. Retrieved from Calhoun http://calhoun.nps.edu/handle/10945/47319.

3. Mission Planning and Execution Model

With these human centric procedures in mind, Rice et al. (2015) explored incorporating the machine aspects of UTACC into the fold of the reconnaissance mission use case. The next step from a systems analysis and design perspective was to create an activity diagram, a depiction of the complex flow of activities occurring within each phase of BAMCIS (Satzinger, Jackson, Burd, 2012). The activity diagram, or mission planning and execution model, is shown in Figure 2. Each row within this model represents a phase of BAMCIS and has specific activities and decision points that must be completed by a component of the UTACC team. These activities are of significant importance to the Coactive Design process. Each one is broken down into its most fundamental capabilities. Each capability is then processed and the outputs come in the form of the system and user interface requirements. (This process will be broken down in further detail during the discussion on Interdependence Analysis Tables.)

Figure 2. Mission Planning and Execution Model



Source: Rice, T., Keim, E. A., Chhabra, T. (2015). *Unmanned tactical autonomous control and collaboration concept of operations.* (Master's thesis). Naval Postgraduate School. Retrieved from Calhoun http://calhoun.nps.edu/handle/10945/47319.

As seen in Figure 2, the BAMCIS steps are separated into their own swim lanes on the left hand side of the figure. The activities that are identified as unique to each step are then listed in a flow chart fashion to the right of the step. This depiction easily guides a system's designer to understand the flow of work from initiation to completion, while each activity fits within the Marine Corps user's troop leading perspective.

4. Task Analysis Worksheets

The activities within Figure 2, Mission Planning and Execution Model, are collective events that define the interdependent relationships between man and machine. Each activity is comprised of many individual subtasks and competencies that require further elucidation. Rice et al. (2015) created multiple reference documents to assist with these explanations, which are referred to as task analysis worksheets. System modelers, while prototyping, can use these documents to understand not only the breakdown of work but also the Marine Corps doctrinal reasoning behind why certain activities must be performed. These documents have been incorporated into the coactive design model.

Figure 3 depicts a generic worksheet and provides descriptions of each field. The worksheets are broken down into three separate sections: administrative data, planning factors, and UTACC actions. The administrative data was utilized within the coactive design process in order to assist with ordering the high-level tasks. Planning factors identified additional tasks and capabilities that needed to be incorporated into the Coactive Design. Finally, UTACC actions were carried over where appropriate and included in the Coactive Design output list of system and interface requirements.

Figure 3. Task Analysis Worksheet Structure

Administrative Data	
Task Name	Self-Explanatory
Task Abbreviation	Author generated abbreviation for the task
Catalog Number	Author generated catalog number for the task
Parent/Previous Task(s)	Catalog number of Parent/Previous Task(s)
Child/Subsequent Task(s)	Catalog number of Child/Subsequent Task(s)
Parallel Task(s)	Catalog number of Parallel Task(s)
Task Summary	A non-technical description of what must be accomplished to complete the task
Reference Documents	Self-Explanatory
Planning Factors	
Threat Analysis	A synopsis of the role of the threat/adversary that affect task performance
Conditions	The variables of the environment that affect task performance
Assumptions	Events assumed to be true in the absence of facts in order to continue planning
Resources	The components and subcomponents of UTACC that will be utilized to complete this task
Specified Tasks	Tasks specifically given by higher headquarters
Implied Tasks	Tasks not specifically stated by higher headquarters but are necessary to accomplish specified tasks
Limitations	Constraints: What must be done Restraints: What cannot be done
Shortfalls	Resources required to accomplish the task that are not organic to UTACC
UTACC Actions	
Inputs	Elements required for the task to be accomplished (e.g., tangible resources, information requirements, etc.)
Process	A non-technical description of the process to assist the modeling team
Outputs	The results of the process given specific inputs
Associated IERs	A list of relevant IERs affected during the process

Source: Rice, T., Keim, E. A., Chhabra, T. (2015). *Unmanned tactical autonomous control and collaboration concept of operations.* (Master's thesis). Naval Postgraduate School. Retrieved from Calhoun http://calhoun.nps.edu/handle/10945/47319

As a future warfighting concept, an important aspect of these worksheets is how they tie to Marine Corps reference documents. Rice et al. (2015) took a deliberate approach to align these worksheets with current Marine Corps tactics, techniques, procedures, and publications. Tying this effort to doctrine increases the likelihood for longevity of UTACC within the Marine Corps and makes it easier to build a training plan aligned with current programs of record.

E. UTACC RED CELL

As a developing technology based warfighting concept, UTACC faces multiple security threats during its design and development phases through to its implementation. Batson's and Wimmer's (2015) thesis, *UTACC Red Cell*, looked at multiple threats and vulnerabilities facing the UTACC system. The objective of the research was to mitigate vulnerabilities and facilitate mission success of UTACC missions (Batson & Wimmer, 2015). Their initial framework for these threats and vulnerabilities was created using the National Institute of Standards and Technology (NIST) Risk Management Framework (RMF) and DOD's Information Assurance Certification and Accreditation Process (DIACAP). The authors noted the framework led to a threat analysis template that broke down UTACC's inherent vulnerabilities and provided security control strategies to mitigate the vulnerabilities. Their findings were separated into non-technical and technical categories (2015). The following quote offers a brief description of each of these categories:

> Within the non-technical category the following security controls emerged as those essential to threat mitigation.
>
> - Policies, procedures and publications must be analyzed to determine specific UTACC system requirements. Requirements lead to the development of system specifications which will drive operational employment, training, and integration of the system.
>
> - The UTACC system security policies and procedures must be developed to meet the requirements of the DOD and USMC. Ensure the UTACC system completes the DIACAP process, which ensures the system meets DOD requirements for IA.

- Adherence to USMC Communications Security (COMSEC) standards and policies which includes physical, cryptographic, transmission, and emission security.

- Training pipeline for leaders, planners, and operators to support the UTACC system employment by a USMC unit.

- Extensive testing and evaluation with operational units. (2015, p. 41)

Technical security control reoccurrences do not form as much of a visible pattern in the research due to the specificity of the technical security controls to the individual threats. The one security control that stands out however is the recommendation for the UTACC system to incorporate semi-autonomous modes of operation. This security control is mentioned in 27 of the 29 templates. Other technical security controls that emerged as those necessary to mitigate threats follow:

- Remote zeroing of software, data, and cryptographic material.

- Employ tamper resistant technology.

- Independent UGV and UAV operations.

- Redundant and encrypted C2 and data links spread across the EM spectrum.

- Ensure the UTACC network communication links are separated from the USMC communication architecture through best practices (boundary, firewall, router access control lists, Virtual Local Area Networks [VLANS]). (2015, p. 42)

These strategies were considered during the initial coactive design process while shaping the system and interface design requirements and should be woven into all future UTACC work. Failure to consider the security and cyber aspects of the system at any stage of the development process could introduce weaknesses that a potential adversary could then exploit.

F. SYSTEMS ENGINEERING

The importance placed on attaining quality system requirements early on with feedback from stakeholders is of critical importance to keeping any large scale, complex and multi-disciplinary system within cost and time constraints (Bernard, 2012). This process is inherently difficult and while much preparation can be achieved up front to set initial requirements, continuous communication between stakeholders and developers is essential throughout the development. Filtering out the issues from the stakeholder's wants and analyzing them against system boundaries, functions, and scenarios leads to the development of realistic requirements. These requirements can then be used in the design process to build out the system architecture.

In the early days of UTACC, MCWL recognized that many of the processes which the UTACC system was being designed to perform seemed repeatable. In other words, many of the tasks and decisions a robot might make while working toward accomplishing a given task were seen again and again, in other similar tasks. Given the scale and complexity of what UTACC was attempting to accomplish, it became necessary to search for ways of streamlining the collection of these requirements. UTACC became interested in the coactive design process as a way to efficiently generate requirements and allow for this streamlining of information flows to the system developers. The benefits of this emergent software design process do not alleviate it from the continuous refinement and communication needed between designers and developers however. This thesis utilizes the coactive design process to produce an initial list of requirements which will need to be adjusted and added to as the system is put through scenario testing.

G. COACTIVE DESIGN

The recent work done by Johnson (2014) on coactive design offered five major contributions to the field of human-robot system design: a fresh design perspective built on interdependence, a more comprehensive understanding of interdependence, a model for human-machine systems, a design method, and a new tool to assist with system design and analysis called the Interdependence Analysis (IA) Table.

1. Interdependence

The foundation of coactive design resides on the concept of interdependence. This concept is a two way reliance, or symbiotic relationship, between people and machines as they work toward the same goal. It is this view that sets the coactive design method apart from other system and software engineering design models. It is viewed by Johnson (2014) as the key element of designing collaborative systems. Johnson (2014) stated that understanding the nature of the interdependencies between humans and machines provides insight into the kinds of coordination that will be required. Johnson et al. (2011) asserted that coordination mechanisms in skilled teams arise largely because of such interdependencies. Interdependence management is therefore the mechanism by which higher level ideas, like collaboration, coordination, and teamwork are achieved (Johnson 2014).

Many modern day human-machine systems share responsibility between both humans and machines, although the automation is unaware of the humans in the activity. Klein et al. (2005) stated that joint activity implies mutual engagements in processes extending in time and space. This statement stresses the importance of both humans and machines and how they interact together to accomplish the goal. Coactive design aims to move away from the common practice of allocating tasks to machines who know little about the overall mission goals or about other tasks that the allocated task is reliant on (Johnson, 2014). Cummings, da Silva, and Scott (2007) noted that current practices ignore the collaboration and collective decision making that is required for successful implementation. Miller (2012) stated that a significant fault with supervisory control frameworks, where tasks are delegated to machines and supervised by humans, is that the rigidly hierarchical task decompositions that they are based upon focus only on the act of delegating and not on the context of the delegation. These studies point ardently to the fact that humans must be integral components of the systems and not merely users of the systems.

Macbeth, Cummings, Bertuccellie, and Surana (2012) stated that most often system users are not considered at the time when algorithm designers create optimization algorithms, and that these optimizations are performed even before the interface designers develop the interface requirements for how the users will interact. With the focus of this thesis to correct that design failure, the users are being considered from the beginning and are being looked at for their mutually supporting roles throughout the task.

Interdependence also shapes the autonomy of the systems. Johnson (2014) stated that the levels of self-sufficiency and self-directedness are very situationally dependent and rely heavily on properly understanding the interdependencies between members of the team in the unique activity in which they are involved. An agent's autonomous capabilities can thus be shaped during design and implementation to enable correct interactions with both people and other agents (Johnson, 2014).

2. Autonomy

Prior to the development of the coactive design methodology, Johnson et al. (2011) investigated the leading popular design approaches to human-machine teaming. Specifically, those approaches were autonomy-centered which presented limited results as they did not capture the necessary give and take relationships between all agents. It is now well known in the automation industry that automating processes does not necessarily simplify complex situations. In fact, it most often has the inverse effect, creating even greater need for control and understanding of the situation early in planning stages.

Johnson (2014) reviewed Parasuraman's, Sheridan's, and Wickens' (2000) scale on the levels of autonomy, which solely focused on the computer's process of decision-making, and viewed it as useless to assisting the designer as it lacked human performance measures. Proud, Hart, and Mrozinski (2003) adapted the Parasuraman et al. (2000) scale by incorporating the necessary human performance measures within the context of the varying levels of autonomy. It parallels the theme of interdependence making it relevant to the coactive design approach, and is presented in Figure 4.

Figure 4. Levels of Autonomy Assessment Scale

Level	Observe	Orient	Decide	Act
8	The computer gathers, filters, and prioritizes data without displaying any information to the human.	The computer predicts, interprets, and integrates data into a result which is not displayed to the human.	The computer performs ranking tasks. The computer performs final ranking, but does not display results to the human.	Computer executes automatically and does not allow any human interaction.
7	The computer gathers, filters, and prioritizes data without displaying any information to the human. Though, a "program functioning" flag is displayed.	The computer anlayzes, predicts, interprets, and integrates data into a result which is only displayed to the human if result fits programmed context (context dependant summaries).	The computer performs ranking tasks. The computer performs final ranking and displays a reduced set of ranked options without displaying "why" decisions were made to the human.	Computer executes automatically and only informs the human if required by context. It allows for override ability after execution. Human is shadow for contingencies.
6	The computer gathers, filters, and prioritizes information displayed to the human.	The computer overlays predictions with analysis and interprets the data. The human is shown all results.	The computer performs ranking tasks and displays a reduced set of ranked options while displaying "why" decisions were made to the human.	Computer executes automatically, informs the human, and allows for override ability after execution. Human is shadow for contingencies.
5	The computer is responsible for gathering the information for the human, but it only displays non-prioritized, filtered information.	The computer overlays predictions with analysis and interprets the data. The human shadows the interpretation for contingencies.	The computer performs ranking tasks. All results, including "why" decisions were made, are displayed to the human.	Computer allows the human a context-dependant restricted time to veto before execution. Human shadows for contingencies.
4	The computer is responsible for gathering the information for the human and for displaying all information, but it highlights the non-prioritized, relevant information for the user.	The computer analyzes the data and makes predictions, though the human is responsible for interpretation of the data.	Both human and computer perform ranking tasks, the results from the computer are considered prime.	Computer allows the human a pre-programmed restricted time to veto before execution. Human shadows for contingencies.
3	The computer is responsible for gathering and displaying unfiltered, unprioritized information for the human. The human still is the prime monitor for all information.	Computer is the prime source of analysis and predictions, with human shadow for contingencies. The human is responsible for interpretation of the data.	Both human and computer perform ranking tasks, the results from the human are considered prime.	Computer executes decision after human approval. Human shadows for contingencies.
2	Human is the prime source for gathering and monitoring all data, with computer shadow for emergencies.	Human is the prime source of analysis and predictions, with computer shadow for contingencies. The human is responsible for interpretation of the data.	The human performs all ranking tasks, but the computer can be used as a tool for assistance.	Human is the prime source of execution, with computer shadow for contingencies.
1	Human is the only source for gathering and monitoring (defined as filtering, prioritizing and understanding) all data.	Human is responsible for analyzing all data, making predictions, and interpretation of the data.	The computer does not assist in or perform ranking tasks. Human must do it all.	Human alone can execute decision.

Source: Proud, R., Hart, J., & Mrozinski, R. (2003). Methods for determining the level of autonomy to design into a human spaceflight vehicle: A function specific approach, *Proc. Performance Metrics for Intelligent Systems, NIST Special Publication 1014,* September 2003.

Figure 4 possesses a level of autonomy axis and an observe, orient, decide, and act (OODA) loop axis. OODA was developed by the military as an attempt to disrupt the enemy's processes of decision making. It is a familiar concept to all Marines, taught early in entry level training and referred to regularly thereafter. Proud, et al. (2003) tailored each level of autonomy to fit the tasks within each function of OODA. The Observe column encompasses gathering, monitoring, and filtering data; the orientation column encompasses analysis, prediction, and interpretation; the decision column refers to ranking options and choosing one; the action column refers to execution of the option chosen (Proud et al., 2003). The levels of autonomy, range from the lowest level, level 1, where the human is fully responsible for all actions performed with respect to OODA, to the highest level, level 8, where the system is fully responsible for all actions (Proud et al., 2003).

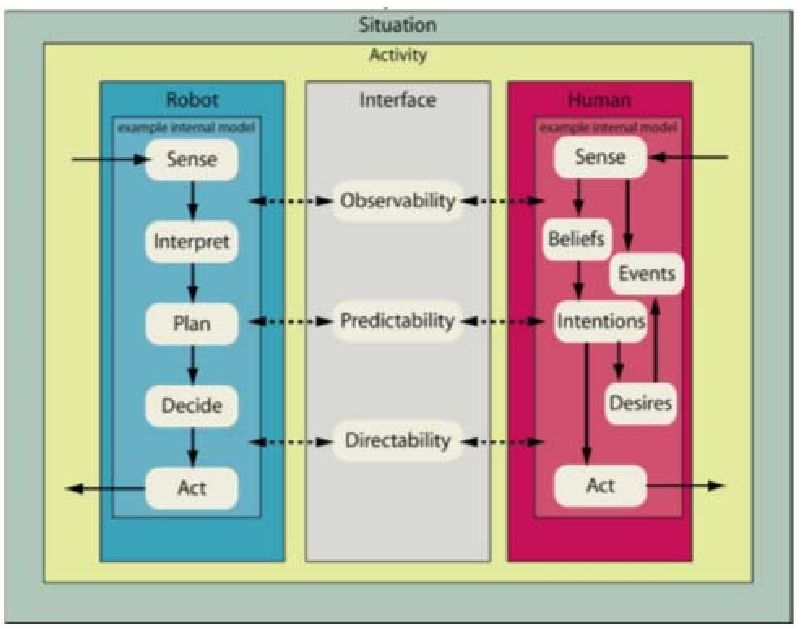
While the coactive design method as developed by Johnson (2014) was developed in the absence of Figure 4, this author used it to conceptualize how to expand the single human-single machine dynamic explored in Johnson's (2014) studies to the more complex dynamic presented within the multiple human-multiple machine, UTACC system. The UTACC system developers can use the construct of Figure 4 as UTACC missions mature beyond what is currently being explored at the time of this writing. It is necessary to stress that the UTACC system is not envisioned to fall within one particular level of this scale but that it should be capable of being placed initially into a level and then dynamically adjusting it throughout any particular mission based on an evolving situation. Being able to meet this demand further stresses the crucial need for understanding the complex interdependencies of the team.

3. Coactive System Model

Having stressed the importance of interdependence and what it means to be interdependent, this thesis moves next to the model for human-machine systems. This model emphasizes how managing and supporting interdependent relationships is possible. This model serves as a means for guiding the designer to relevant issues needing to be addressed, defines appropriate specifications, and also aids in evaluating alternatives.

Johnson et al. (2014) viewed Fong's (2001) collaborative control method as the most descriptive model existing in literature at the time of their research. Fong's (2001) innovation was in stating that the human should be permitted to make perceptual or cognitive decisions for the robot through a user interface (UI) that the robot provides inputs to. Fong's (2001) model considered the internal processes of the robot and how they manifested to the user as opposed to depicting the robot as a black box of uncertainty. In modeling how perception and cognition occurred in the robot there were ways to vary how the human could interact with them (Fong, 2001). Fong's (2001) model was suited to individual activity—as opposed to joint activity—and how the simple tasks were handed off from human to robot. This method more closely resembled teleoperation of a robot by a human as opposed to what Johnson et al. (2014) sought to model, which was an interdependent relationship through the conduct of a joint activity. The Johnson et al. (2014) model highlights the importance of internal processes similar to Fong's (2001) work but with the additional requirements necessary to conduct joint activity: observability, predictability, and directability (OPD); it is presented in Figure 5.

Figure 5. Coactive System Model



Source: Johnson, M. (2014). *Coactive design: Designing support for interdependence in human-robot teamwork*. Doctoral dissertation, Delft University of Technology-Mekelweg/Netherlands.

4. Observability, Predictability, and Directability

The following quote from Johnson's (2014) work clarifies what it means to be observable, predicable, and directable:

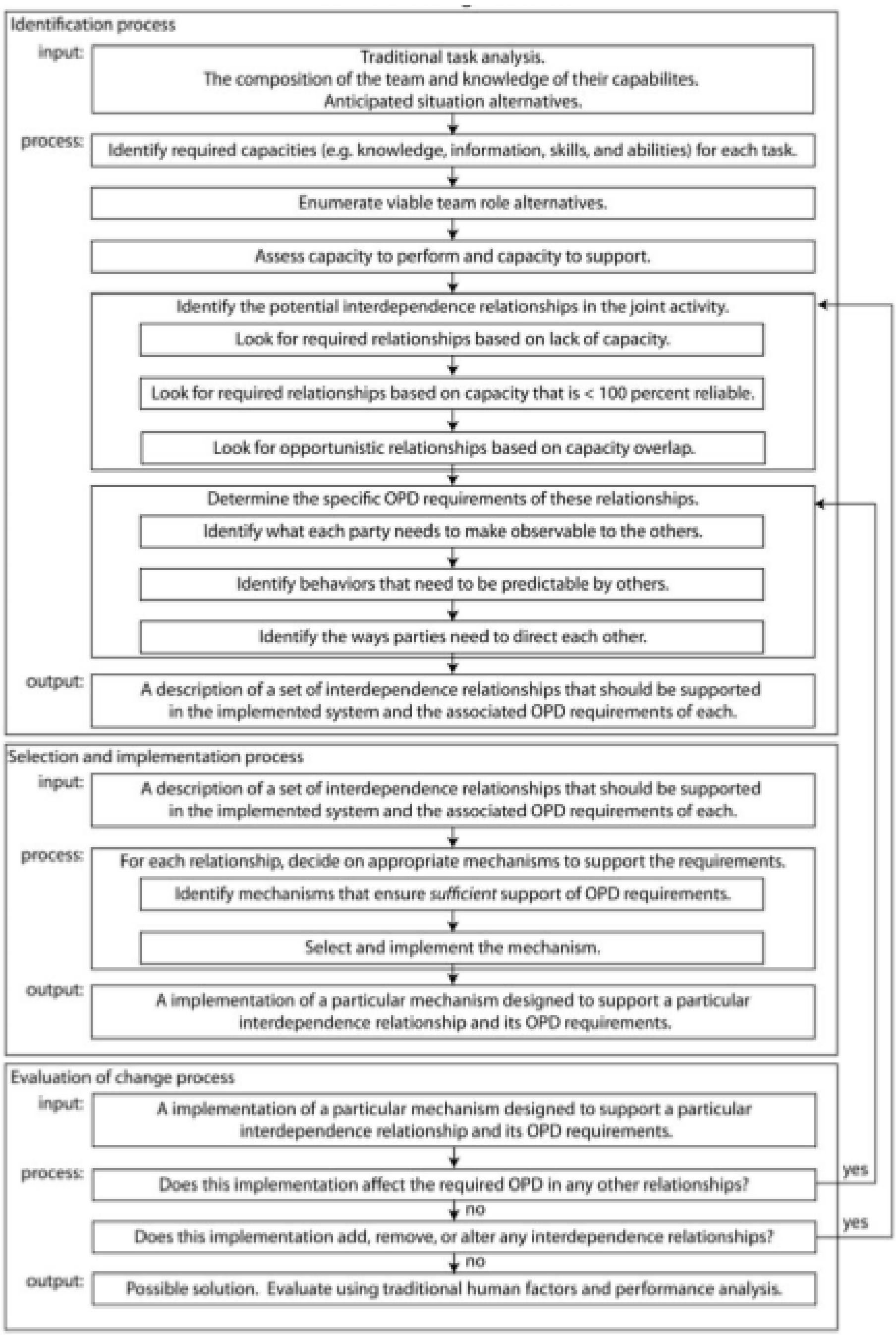
> Observability means making pertinent aspects of one's status and knowledge of the team, task and environment observable to others. Observability also involves the ability to observe and interpret pertinent signals. It plays a role in many teamwork patterns e.g., monitoring progress and providing backup behavior.
>
> Predictability means one's actions should be predictable enough that others can reasonably rely on them when considering their own actions. Predictability also involves considering other's actions when developing one's own. It is essential to many teamwork patterns such as synchronizing actions and achieving efficiency in team performance.
>
> Directability means one's ability to direct the behavior of others and complementarily by directed by others. It includes explicit commands such as task allocation and role assignment as well as subtler influences, such as providing guidance or suggestions or even providing salient information that is anticipated to alter behavior, such as a warning. Teamwork patterns that involve directability include such things as requesting assistance and querying for input during decision making.
>
> By using the OPD framework as a guide, a designer can identify the requirements for teamwork based on which interdependence relationships the designer chooses to support. The framework can help a designer answer questions such as 'What information needs to be shared,' 'Who needs to share with whom,' and 'When is it relevant.' The goal of the designer is to attain *sufficient* OPD to support the necessary interdependent relationships. (2014, pp. 68-70)

This OPD framework shifts the focus from one individual component, either the robot or the human, to the team components and how they both affect one another (Johnson, 2014). The framework separates individual task accomplishment from teamwork. The interface represents the mechanism required to support this interdependence (Johnson, 2014).

5. Coactive Design Method

Conveying abstract concepts like coordination, cooperation, and collaboration into system designer friendly forms, or system requirements implemented through control algorithms, interface features, and behaviors, is challenging. The coactive design method translates these complex concepts into useful system requirements by managing interdependent activities (Johnson, 2014). With an understanding of what it means to be interdependent, the OPD requirements, and the Coactive Design Model it is now appropriate to consider in detail the Coactive Design Method, illustrated in Figure 6.

Figure 6. Coactive Design Method



Source: Johnson, M. (2014). *Coactive design: Designing support for interdependence in human-robot teamwork.* Doctoral dissertation, Delft University of Technology-Mekelweg/Netherlands.

As seen in Figure 6, the Coactive Design Method has three main processes: identification, selection and implementation, and evaluation of change. Each process is then further broken down into inputs, sub-processes and lastly outputs. The design of Figure 6 can be misleading as the steps seem to flow in a stepwise fashion from block to block resembling a waterfall design process. When modeling processes with a waterfall design, the requirements are mostly understood upfront and allow developers to move on to subsequent phases without needing to revisit previously completed phases (Satzinger et al., 2012). However, the feedback loops to the side of the figure are of critical importance in understanding the process and must be fully conveyed to all stakeholders invested in the system's development. These loops illustrate that the Coactive Design Method contains many adaptive elements that evolve through iteration, which is what Satzinger et al. (2012) considers spiral modeling. This adaptive, spiral modeling process not only suggests that the identification, selection and implementation, and evaluation processes of the Coactive Design Method be repeated but necessitates repetition in order to produce solutions that more accurately capture the interdependent activity.

a. Identification Process

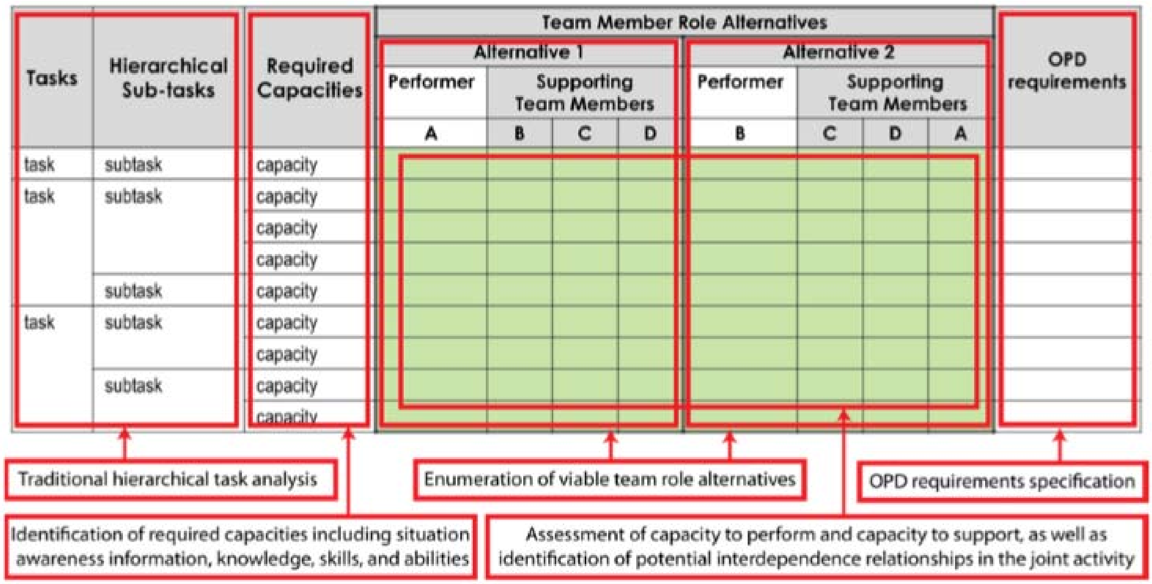
Johnson (2014) differentiated the Coactive Design Method from traditional task analysis techniques through its unique analysis of interdependence by:

- Allowing for soft constraints
- Allowing for more types of interdependence than just task dependency
- Representing other participants in the activity by name or by role
- Allowing for assessment of capacity to perform
- Allowing for assessment of capacity to support
- Allowing for consideration of role permutations

The identification process within Coactive Design is made possible through an analysis tool that Johnson et al. (2014) refers to as the Interdependence Analysis (IA) Table, Figure 7. This author adapted the Johnson et al. (2014) Interdependence Analysis

Table to meet the larger, many human-many machine, UTACC teaming environment. The adapted UTACC IA Table is presented in the following chapters of this thesis.

Figure 7. Interdependence Analysis Table



Source: Johnson, M. (2014). *Coactive design: Designing support for interdependence in human-robot teamwork.* Doctoral dissertation, Delft University of Technology-Mekelweg/Netherlands.

Figure 6, the Coactive Design Method, provides guidance on how to navigate and manipulate the IA Table depicted in Figure 7. The identification process begins with traditional task analysis. The left most columns of the IA Table break down tasks into manageable granularity. Capacities are defined as the knowledge, skills, and abilities that are necessary for the tasks. These include perceptual, decision making, and specific action needs (Johnson, 2014). The next sections, moving right across the table, enumerate the team role alternatives by identifying the primary actor that will be accomplishing the task and the remaining team mates in supporting roles. Alternatively, a different actor may serve as the primary with a different cast of agents in supporting roles. In listing these alternatives it becomes possible to identify the best suited team member for fulfilling a task and communicates that a level of support is required by the rest of the team. After alternatives were determined, Johnson (2014) then assessed the individual's ability to provide the required capacity or ability to support the performer. This assessment is made possible through the use of the following color coding scheme (Figure 8).

Figure 8. Interdependence Analysis Coloring Scheme

Team Member Role Alternatives	
Performer	Supporting Team Members
I can do it all	My assistance could improve efficiency
I can do it all but my reliability is < 100%	My assistance could improve reliability
I can contribute but need assistance	My assistance is required
I cannot do it	I cannot provide assistance

Source: Johnson, M. (2014). *Coactive design: Designing support for interdependence in human-robot teamwork.* Doctoral dissertation, Delft University of Technology-Mekelweg/Netherlands.

It is important to note the colors take on different meanings with respect to describing the performer verses the supporting team members. The performer column breaks down the individual's capacity to perform a task. Colors in the supporting member column indicate potential to support the performer—and not the ability of that team member to do the task themselves. A simple example of how the differences play out may illustrate the point further. In the case of a robot as the performer and a human as a supporter, the robot may be able to search a room while looking for an object all on its own. However, introduce a tall table into the room and place the object on it, out of view of the robot, and the robot is unable to complete the task with 100 percent reliability. Having a human check the table would improve that reliability. Shading in the IA Table would then color the performer column with yellow and the supporting column with yellow.

Coloring patterns can be analyzed once all performer and supporting alternatives are complete providing the designer insight into the interdependence of the relationships (Johnson, 2014). Figure 9 summarizes the different color combinations and what the corresponding color combinations represent.

Figure 9. Potential Interdependence Analysis Table Color Combinations with Interpretations

Team Member Role Alternatives		Interpretation
Performer	Supporting Team Members	
A	B	
Reliable	Soft Interdependency	Independent operation by performer is a viable option, but assistance could improve efficiency.
		Independent operation by performer is a viable option, but assistance could improve reliability.
	Must be independent	Independent operation by performer is necessary.
Potential Brittleness	Soft Interdependency	Performer is < 100 percent reliable, but assistance could improve efficiency.
		Performer is < 100 percent reliable, but assistance could improve reliability.
	Must be independent	Performer is < 100 percent reliable, and no assistance is possible from this team member.
Missing Some Capacity	Soft Interdependency	Performer requires assistance, team member can provide it, and assistance can improve efficiency.
		Performer requires assistance, team member can provide it, and assistance can improve reliability.
	Hard interdependency	Performer requires assistance, and team member can provide it.
Unachievable		Performer requires assistance, but none is possible.
		Performer cannot do task.

Source: Johnson, M. (2014). *Coactive design: Designing support for interdependence in human-robot teamwork.* Doctoral dissertation, Delft University of Technology-Mekelweg/Netherlands.

The following quote from Johnson (2014) illustrates the importance in understanding the color combinations:

> Overall, the colors in the first column provide an understanding of how the performer would fare if required to meet the capacity requirement autonomously. Colors other than green in the performer column indicate some limitation of performer, such as potential brittleness due to reliability (yellow), hard interdependency due to lack of capacity (orange), or just a complete lack of capacity (red).
>
> The supporting team member columns provide an understanding of what type of interdependence relationships could potentially be supported. The color red in these columns indicates that there is no chance for assistance. This makes the performer a single point of failure. If the performer is less than 100 percent reliable, you will have a brittle system. However, if you can provide support for interdependence then you can avoid the single point of failure. Colors other than red in the supporting team member column indicate potential required (orange) or opportunistic (yellow and green) interdependence relationships between team members. The hard interdependencies are usually easy to identify because you cannot complete the task without it. Soft interdependencies tend to be more

> subtle, but provide valuable opportunities for teamwork and alternative pathways to a solution. (2014, pg.77)

It is thanks to this relatively simple set of color combinations that repeatable patters in behaviors and support relationships are made easily identifiable. As a result, Johnson (2014) stated that it becomes increasingly simple to identify the following:

- Agents lacking capacity and those that can offer it
- Agents lacking 100 percent reliability and those that can supplement it
- Capacity overlaps that provide opportunistic relationships

Johnson (2014) stated that the OPD requirements derive from these interpretations and answer the questions:

- Who needs to observe what, from whom?
- Who needs to be able to predict what?
- How do members need to be able to direct each other?

After these requirements have been identified, a system's designer will possess a set of interdependent relationships that must be supported by the system and the requirements that make those relationships possible. This completes the identification process, the first of three processes, within Figure 6, the Coactive Design Method. The remaining two processes, the selection and implementation process and the evaluation of change process, keep to their respective name sakes and require little explanation. The selection and implementation process involves finding design mechanisms capable of meeting the requirements obtained in the identification process and implementing them. The evaluation of change process consists of ensuring the mechanisms chosen to support the requirements adequately meet expectations and that no secondary effects on other OPD relationships have resulted from their implementation. These feedback loops, as indicated in Figure 6, lend themselves to an iterative, spiral design process as described by Satzinger, et al. (2012). If other OPD relationships are affected or if additional tasks or capabilities are identified they need to be inserted into the identification process and the Coactive Design Method rerun. Once all possible solutions have undergone and passed their performance and human integration tests the system will be ready for deployment.

H. CHAPTER CONCLUSION AND SUMMARY

This chapter began with the UTACC vision and overview and stated the need for continuing the exploratory initiative, expressed in EF21. There were two major bodies of work analyzed and merged together under this thesis' research. The first body of work was Rice's et al. (2015) UTACC Concept of Operations which possesses the Mission Execution and Planning Model and the Task Analysis Worksheets. The second effort analyzed during this research was Johnson's (2014) Coactive Design Method, including an iterative Coactive Design Model and the Interdependence Analysis Tables.

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III. RESEARCH METHODOLOGY

In 2013, the Marine Corps Warfighting Laboratory (MCWL) began exploring the Unmanned Tactical Autonomous Control and Collaboration (UTACC) initiative. Rice et al. (2015) and Batson and Wimmer (2015) pioneered the early development of the UTACC concept and validated the concept's viability by providing initial concept designs and threat and vulnerability assessments. In the short term, these results meant the continuation of the program and the exploration of capturing what were traditionally human to human interactions and the translation of these interactions when a machine is substituted into the equation. The successful achievement of this end state sets the conditions for the final, long term configuration of UTACC, laid out as a "decision-centric, semi-autonomous, distributive, multi-agent, multi-domain robotic system" (SOW, 2014).

With this configuration in mind for the foundation of UTACC, the next step forward was to determine the special information exchange requirements between Marines and machines that ought to be implemented into the UTACC system. Coactive design was chosen as the method for documenting these exchanges, since research indicated that it was the only systems engineering process available that enabled requirements generation for robot-Marine teaming. This thesis looked at the feasibility of incorporating coactive design as a repeatable process within the UTACC Enterprise Engine. To accomplish the incorporation of Coactive Design, the lead architect of the original Coactive Design Method, Dr. Matthew Johnson, was sought out to teach this author how to apply the method to the UTACC initiative. The author conducted two separate trips to the Institute of Human Machine Cognition (IHMC) where Johnson continues his work with Coactive Design. The first trip sought to educate the author on the process and the second trip validated the application of this knowledge to UTACC.

A. DEFINITION OF THE PROBLEM

The Rice et al. (2015) Mission Planning and Execution Model and Task Analysis Worksheets were well suited to the initial proof of concept. However, there are a number of reasons why the Rice et al. (2015) model, as a standalone, should not be used by UTACC system designers for future consideration. The work of Rice et al. (2015) was limited in scope as it only analyzed the reconnaissance mission and not indicative of reconnaissance missions in general. The UTACC system is envisioned to be adaptive to a wide range of dynamically changing missions.

The Mission Planning and Execution Model also failed to record the level of interaction between agents necessary to complete tasks within a larger mission set. Without this information the reliance on specific environmental conditions being met before work can be accomplished is high. It is the identification of perceptual, cognitive, and physical needs that provides insight into what interdependencies are at play and which agents are best suited to perform and support tasks. The interdependent framework of the Coactive Design Model and the Interdependence Analysis Tables provide the level of responsiveness that a system like UTACC needs to be built around. An agile and system conscious design method like coactive design is more efficient in both the short and long term; Coactive Design's main selling point is that it delivers design mechanisms to developers that more accurately capture the system as a whole.

At the time of this writing a second round of UTACC demonstrations has been planned. The goal of the demonstrations is to exhibit a few new features of the systems but the context of a controlled reconnaissance mission remains the same. The existing work of Rice et al. (2015), specifically the Mission Planning and Execution Model, became a natural starting place for this research. The author attempted to incorporate as much of that work into the Coactive Design Model as possible. The successful merger of these two models would aid in the increased dissemination and acceptance of the new model with respect to those involved with the UTACC initiative and the prospective user community. This preservation of the existing UTACC knowledge base would send a message more in line with a software upgrade rather than an operating system switch, and this would result in being viewed as only minimally invasive to MCWL.

B. MODIFYING COACTIVE DESIGN PROCESSES FOR UTACC

During the first trip to IHMC, the author gained insight into how the Coactive Design Method operated within the context of IHMC's unique operating environment. That body of knowledge is summarized in the Chapter Two literature review. While many similarities exist between IHMC's work and that which UTACC aims to achieve, the UTACC operating environment presents many unique challenges that were not relevant to IHMC.

1. UTACC Interdependence Analysis Table

As an illustration of this point, the IHMC construct revolved around a single humanoid robot, whereas the UTACC initiative seeks a multi-domain, multi-agent system. Despite these differences, the Coactive Design Method as proposed by Johnson (2014), and illustrated in Figure 6, remained unaltered. However, the analysis tool utilized to accomplish this method had to be tailored accordingly. The modified UTACC Interdependence Analysis (IA) Table with cell descriptions is listed in Figure 10.

Figure 10. UTACC Interdependence Analysis Table

				Option 1			Option 2			Option 3			
BAMCIS STEP	Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Troop Leading Step	(A) Main Task	(A.1) Subtask of Main Task (A)	(A.1.1) Capacity required for (A.1)										Mechanisms, interface design elements, etc. that meet the Observability, Predictability, Directability requirements synthesized through the analysis of the interdependent teaming role alternatives.
			(A.1.2) Capacity required for (A.1)										
		(A.2) Subtask of Main Task (A)	(A.2.1) Capacity required for (A.2)										
		(A.3) Subtask of Main Task (A)	(A.3.1) Capacity required for (A.3)										
	(B) Main Task	(B.1) Subtask of Main Task (B)	(B.1.1) Capacity required for (B.1)										
		(B.2) Subtask of Main Task (B)	(B.2.1) Capacity required for (B.2)										
			(B.2.2) Capacity required for (B.2)										

Adapted From: Johnson, M. (2014). *Coactive design: Designing support for interdependence in human-robot teamwork.* Doctoral dissertation, Delft University of Technology- Mekelweg/Netherlands.

The UTACC Interdependence Analysis Table also reflects the desire to maintain as much of the pre-existing concept design from the Rice et al. (2015) thesis work as possible. Incorporating the essentials of the Mission Planning and Execution Model developed by Rice et al. (2015), required several modifications to the original IA Table as developed by Johnson (2014). An additional column was added to the front of the table which groups tasks within the Marine Corps Troop Leading Steps. Alternative teaming roles were expanded to allow for multi-domain, multi-robotic agents, including the potential for the human to serve as the performer with the robotic elements serving in the support roles. The most developed UTACC use case allows for multiple air and multiple ground robots, as well as, multiple humans. However, this work distilled the UTACC use case down into a single unmanned ground system (UGS), unmanned air system (UAS), and human element. The three different teaming role alternatives are then a rotation of performer among the three agents while the remaining agents serve in support roles.

2. UTACC Color Scheme

When the IA table was modified to meet the needs of the UTACC initiative, the author noticed an expanding level of complexity, corresponding to the need to analyze three teaming role alternatives as opposed to two in the Johnson (2014) work. By eliminating many of the possibilities that were inherently not feasible, the author could more easily sift through numerous possibilities of interdependent relationships and interpret more accurately what the color combinations represented. Figure 11 depicts the modified UTACC IA Color Scheme.

Figure 11. UTACC Interdependence Analysis Color Scheme

Performer	Supporting Team Member
I can do it all	My assistance could improve efficiency
I can do it all but my reliability is < 100%	My assistance could improve reliability
I can contribute but need assistance	My assistance is required
I cannot do it	I cannot provide assistance
Not applicable	Not applicable

Adapted from: Johnson, M. (2014). *Coactive design: Designing support for interdependence in human-robot teamwork.* Doctoral dissertation, Delft University of Technology- Mekelweg/Netherlands.

The color gray added to the Interdependence Analysis Color Scheme makes it easier to analyze interdependent teaming role alternatives. Simply, the color gray represents the agent is not in the role of the performer or the supporting team member and is not applicable for consideration. An example of when this color simplifies analysis of teaming role alternatives follows. Figure 12 helps illustrate the example.

Figure 12. Example UTACC IA Color Scheme

	Option 1			Option 2			Option 3		
Capacities	UAS	UGS	M	UGS	U AS	M	M	UAS	UGS
resolve airspace									

The example explains how the author applied the color scheme to the capacity of resolving airspace. In this case, the UAS must be the performer. So the alternatives where the human and UGS are the performer, the alternates would be completely gray and thus eliminate the need to analyze them later in the Coactive Design Method. Also, as the UGS is restricted to the ground, it would be unable to help the UAS resolve airspace and therefore would be shaded gray under the supporting team member column. This would leave only the human in the role of supporting the UAS as lacking a color. In this manner, eliminating seven out of nine relationships with regard to one capacity greatly reduces the complexity of the resulting color schemes and allows the coactive designer to focus their attention on this one interdependent relationship.

C. CHAPTER SUMMARY

This chapter began by outlining the issues with the old Mission Planning and Execution Model, as developed by Rice et al. (2015). Coactive Design was selected to resolve these issues and serve as the system's development method for the duration of the UTACC program. Coactive Design required slight process modifications in order to seamlessly fuse UTACC concepts. Among the most significant modifications were the minor alterations made to the IA Tables framework and the additional category added to the IA Color Scheme. An example was provided to illustrate how these modifications accommodated the UTACC construct by simplifying analysis, despite UTACC possessing a larger framework than Coactive Design was originally designed to handle. The next chapter will explore the results of applying the Coactive Design method to UTACC.

IV. UTACC COACTIVE DESIGN RESULTS

This section delivers an executive overview of the results from applying Coactive Design to Unmanned Tactical Autonomous Control and Collaboration (UTACC). This executive summary will focus on major components of the Interdependence Analysis (IA) Tables, many of which were supported by the Task Analysis Worksheets of Rice's et al. (2015) work.

The work flow analyzed by the UTACC Coactive Design was modeled off of the Marine Corps Troop Leading Steps, a work break down structure organic to the Marine Corps that forms the basis of mission planning. The steps of this structure spell out the acronym BAMCIS and consist of: Begin the Planning, Arrange for Reconnaissance, Make Reconnaissance, Complete the Plan, Issue the Order, and Supervise Activities. An IA Table was developed for each of these steps.

Due to the size of the IA Tables, they had to be partitioned off to allow for discussion in this format. Depending on the number of tasks within each BAMCIS step, a particular IA Table may be split into many sections. These partitions also serve the purpose of incrementally stepping through the way the IA Tables were created. This presentation style will assist any follow on Coactive Designer in understanding the author's train of thought, which was heavily influenced by his infantry experience. All of the resultant IA Tables' tasks are stacked, decomposed and analyzed within the alternative teaming options and possess observability, predictability, and directability (OPD) requirements. This chapter will present the IA Tables with a discussion of the OPD requirements and key takeaways for developers.

A. BEGIN PLANNING IA TABLES

The first phase of the Troop Leading Steps work flow is the B in BAMIS: begin planning. The tasks associated with UTACC in this phase involve initiating the system and setting preferences and then entering mission parameters based on a directive received from a higher level command, thus initiating a mission.

1. Begin Planning: Initiate System and Set Preferences

Initiating the system and setting preferences involves the subtask of setting the desired level of autonomy. This subtask is broken down into defining the general nature of each human-machine relationship and having the system understand its role within each different level. Figure 13 depicts this task decomposition and provides the OPD requirements for achieving it.

Figure 13. Begin Planning IA Table: Initiate System and Set Preferences

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Initialize System/ Set Preferences	Set desired level of autonomy	Define the general nature of each H-M relationship										Conduct subsystem checks to ensure that the current status of all UTACC components is known and any repairs or exchanges can be made prior to mission execution. Calibrate natural language processing and human motion recognition sensors to users. Incorporate all major subsystems to ensure good communications links are established between components. Establish communications with Higher command. Level of autonomy will be based on team parameters (number of agents participating within the teaming environment). A discussion on levels of autonomy needed. Depending on mission, human may want more of a tele operate mode or a collaborative mode based off of cues and alerts or a complete task handoff with the robots. The UTACC system should allow for changes to the level of autonomy mid mission. There should be a default level preprogrammed so that in the absence of human input the system is still preforming. This default level should come built in, however, the operators should have controls to modify depending on mission. Options include return to base or return to last location with good communication link, or continue scanning area until complete, or wait x number of minutes past last alert before RTB. Interface should prompt for user to enter parameters.
		Understand role within each different level										As this autonomy level is modified by the human either before or during activity, so to must the robots requirements to interact with the team. Similarly, if the robot is operating under a more restrictive setting where communication is required and not being met it will roll into a contingency setting (as defined above in the "Define the general nature of each H-M relationship" capability block.

The OPD requirements drawn from this IA Table are concerned with calibrating the system, identifying all participating teammates, and establishing the desired level of autonomy that is initially required of the system. Coordinating instructions for events that concern contingencies (e.g., loss of communication with the robots, and necessity to adjust the level of autonomy mid-mission) are listed as well. The process of facilitating the interface design is also mentioned in the table.

2. Begin Planning: Enter Mission Parameters

The mission parameters have been delineated in a format that all Marines are familiar with, known as the *Five Paragraph Order (5PO)*. OSMEAC is the acronym used to teach the 5PO and stands for Orientation, Situation, Mission, Execution, Administration and Logistics, and Command and Signal. Each has been assigned as a subtask and is further broken down within the capacity field of the IA Tables.

The Marine unit leader must receive the tasking directive and relay it to his unit before setting them in motion. As UTACC is now a member of the unit, that unit leader must now relay the directive to it as well. It is perceived that entering these parameters will benefit the unit leader's understanding of the mission and better facilitate the translation of the mission to the human teammates, as well.

a. Five Paragraph Order: Orientation and Situation

While the orientation is not one of the essential five paragraphs within the 5PO, it is necessary for properly framing the mission. With regard to UTACC, that translates into ensuring the system understands the operating area. An effective orientation sets the stage for the situation which has an enemy and a friendly component. Figure 14 depicts the O and S portions of this task decomposition and provides the OPD requirements for achieving it.

Figure 14. Begin Planning IA Table: the OSMEAC "O" and "S"

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Enter mission Parameters: "O-SMEAC": Orientation, Situation, Mission, Execution, Administration/Logistics, Command/ Signal.	Understand the Orientation	Understand the operating area / box										The orientation should be simple and brief. It includes the present location, direction of attack and objective. It may include a brief description of major/important terrain features. ie. a mountain or river. Further described in the Arrange for Recon>> Conduct initial Mapping for Orientation>> Scan area between origin and Objective>> Understand size of Area.
	Understand the Situation	The Enemy Situation										Enemy Forces. Information about the enemy contained in this subparagraph should be the culmination of intelligence provided by higher headquarters and information gathered which pertain to the accomplishment of the mission. The Enemy Forces situation can be issued using the acronyms SALUTE, DRAW-D, EMLCOA, EMDCOA.
		The Friendly Situation										Friendly Forces. Information contained in this subparagraph is obtained directly from your higher commander's order. It contains the missions and locations of higher, adjacent, and supporting units. Information should be limited to that which subordinate leaders need to know to accomplish their assigned mission.

The OPD requirements associated with achieving the O and S are concerned with input fields on the user interface. The Marine must provide this information in order to convey where the system will be operating, if friendly forces or the effects of friendly forces will be experienced, and whether or not to anticipate resistance from perceived threats.

b. Five Paragraph Order: Mission

The mission paragraph is where the overall mission of the team is described— not to be confused with the individual assignments of the team members, which are referred to as tasking statements and follow later in the 5PO. Also of note, a tactical task is the term for the action to be conducted during a mission. All mission statements and tasking statements must contain one, and only one, tactical task. A list of published tactical tasks with clear definitions that permit Marines the ability to quickly communicate desired actions and outcomes can be found in Marine Corps doctrinal publications like MCRP 5–12a: Operational Terms and Graphics. New tactical tasks may need to be developed as systems find their way onto the battlefield. Such discussion is beyond the scope of this thesis. Understanding the mission of the system within the related mission of the team is the capacity described in Figure 15.

Figure 15. Begin Planning IA Table: the OSMEAC "M"

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Enter mission Parameter "OSMEAC": Orientation, Situation, Mission, Execution, Admin / Logistics, Command/ Signal.	Understand the Mission (type)	Understand the mission of the UXVs related to mission of team										The mission statement (this is the mission statement for the UTACC team, not the individual robot which will come under tasks in the Execution Block of O-SMEAC) is a clear and concise statement (one simple sentence) of what the unit is assigned to accomplish. It expresses the unit's primary task and purpose represented by the "five Ws" — When (time), Who (unit), What (task), Where (grid), and Why (purpose) for the mission assigned. The task describes the action to be taken while the purpose describes the desired result of the action. Of the two, the purpose (Why) is predominant. The purpose of the mission statement is always represented by the words: in order to (and can be abbreviated by IOT). While the situation may change, making the task obsolete, the purpose is more permanent and continues to guide actions. The Main Effort is the commander's "bid for success" and is the one subordinate unit (e.g. fire team) assigned the most important task to be accomplished by the higher unit (e.g. squad). The commander ensures the success of the main effort by providing it with a preponderance of support (i.e. "weighting the main effort") and designating corresponding "Supporting Effort" tasks to the remaining units. Only one (1) unit is designated as the Main Effort and must be identified in it's mission statement. A preprogrammed mission menu with selectable options for each of the 5 Ws is needed. Who : UTACC Team. What: tactical task (defined in below block) Where: MGRS; When: a menu box with a calendar and digital military clock allowing the human to select inputs. Why: omitted for UTACC inability to understand mission importance.
		Tactical tasks										A tactical task is a defined action word or phrase that meets specified requirements and drives toward a specific end state. May need to derive new tactical tasks for robot missions (ie. Conduct a Route Recon or Zone or Area Recon). Provide a list of current tactical tasks as an appendix. UTACC should understand

The OPD requirements listed in Figure 15 describe a list of input fields needed on the user interface that will shape how and what tasks the systems will perform. The additional details will help ensure that the system's actions (which will be specified in the tasking statements) are nested within the team's mission.

c. *Five Paragraph Order: Execution*

The next paragraph of the 5PO is Execution and revolves around the physical actions, setting conditions, and sequencing of events. In order to convey this information, the paragraph is broken down into several subparagraphs: the Commander's Intent within the Concept of Operations (CONOPS), the Scheme of Maneuver (SOM) within the CONOPS, the Fire Support Plan (FSP) within CONOPS, Tasking Statements, and Coordinating Instructions. Figure 16 depicts this breakdown and the OPD requirements necessary to achieve them. Further, this establishes the shared objective between Marines and machines.

Figure 16. Begin Planning IA Table: the OSMEAC "E"

Tasks	Subtasks	Capacities	Option 1 UAS	Option 1 UGS	Option 1 M	Option 2 UGS	Option 2 UAS	Option 2 M	Option 3 M	Option 3 UAS	Option 3 UGS	OPD requirements
Enter mission Parameters: "O-SMEAC": Orientation, Situation, Mission, Execution, Admin / Logistics, Command / Signal.	Understand the Execution (Concept of Operations, Tasks, Coordinating Instructions)	Concept of Operations: Commander's Intent										Concept of Operations. General explanation of the tactical plan. Includes the Commander's intent and a brief scheme of maneuver from start to finish, type of attack, and fire support plan. Commander's intent is critical for the human to understand so that the mission will get accomplished in lieu of changes
		Concept of Operations: Scheme of Maneuver										Scheme of Maneuver: is the big picture on how all subordinate units will conduct the plan. When given to humans, it is described in general, and in anonymous terms without identifying specific units.
		Concept of Operations: Fire Support Plan										Fire Support Plan. Describes how fire support will be used to complement the scheme of maneuver. The Fire support plan ties in directly with the scheme of maneuver. A menu for fire support control measures should be accessible and allow for click and drop or grid input. These include fire capable positions of indirect fire agencies (mortars, artillery) as well as for initial points (IPs) for fixed wing aircraft and battle positions (BPs) for rotary wing close air support. Current data for ordinance including time of flight, altitudes, trajectories, effective casualty radii, probability of injury should be preprogrammed into the UTACC system.
		Tasks										Tasks: Task statements are a subordinate unit's mission statements, and as such, should be written in the same manner as any mission statement, with the 5 W's. When a subordinate unit is designated the main effort (or supporting effort 1, 2, etc.) it must be stated in the unit's tasking statement. The relevancy of this block will provide all units an understanding of what their respective roles are and how those roles directly affects the other units.
		Coordinating Instructions										Coordinating Instructions include: Time of Attack, Base Unit, Order of Movement, Security, Tactical Control Measures, Route to the Objective. This information will be useful for prioritizing work and optimizing performance. Each of these items should be displayed with an adjustable graphical user interface box with dropdown box filled with possible options in appropriate format (i.e. time of attack box will prompt a calendar for date selection and a digital clock in military time, base unit box will show all available humans and machines within team and will allow for prioritization of as many members as necessary to designate hierarchy of command; order of movement will indicate which other units if any will be participating during a given mission; security box should indicate which robots were designated for work away from the team and which robots will remain within the "security formations"; a list of possible tactical control measures should be available in a menu box that could be placed either by dragging or grid input.

Many of the perceived benefits of including all of the elements of the 5PO into this IA Table relate back to the influence they have over the thought processes of the unit leader. While a particular element may or may not directly impact the actions of a team member (whether Marine or machine), they remain a part of the planning process for the role they play in the larger picture. Within the execution paragraph it becomes easy to develop tunnel vision and hone in on tasks; that is, after all, what the unit leader will be ordering the systems and Marines to go out and accomplish. It is the other elements of this paragraph that tie the otherwise disjointed tasks together. The OPD requirements described in Figure 16 help guide the design of the interface to quickly guide the user through developing their plan.

d. Five Paragraph Order: Admin / Logistics and Command / Signal

The final two paragraphs of the 5PO are the administration and logistics plan and the command and signal plan. True to their names, these paragraphs deal with personnel and robot accountability, resupply and refueling, communication architectures, and succession of authority or command relationships. The capacities listed in Figure 17 detail these points and provide the OPD requirements necessary to achieve them.

Figure 17. Begin Planning IA Table: the OSMEAC "A" and "C"

		Option 1			Option 2			Option 3			
Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Understand the Administration and Logistics Plan	define number of humans and robots collaborating in teaming environment.										The UXVs will need a way to sense friendly units in the field including those without a communication link/ feedback loop if tracking all of them is required. (potential for passive RFID chips that respond to an active signal sent out from the UXV. Enemy spoofing and jamming threat is area of future research if this option is desired. If monitoring of individuals within the team is unnecessary then updating the teams' general location during communication exchanges may suffice.
	define roles of each human and robot as they apply to team										These roles should be part of a preprogrammed menu on the interface. (ie. human 1, teleoperate. Human 2, answers all alerts and ques, UAV 1 independent scan area. UAV 2 scan with coordination from UGV1. humans 3-5 non-collaborators. all UXVs track all 5 human statuses.)
	define refuling and RTB points if different from origin										UXV may need to return to base (for any number of reasons including loss of communications link, mission critical sensor malfunction, inclement weather, etc). A separate issue, refueling, which could utilize the same or different locations from the input RTB location should be provided to the robots. Interface should have preprogrammed options (RTB end mission early, RTB mission complete, and RTB refuel) once selected the human should provide a grid to where the robot is to return in the event of one of those triggers occuring. A default last known take off location should be recorded in the event that this step is omitted.
Understand Command and Signal Plan	Command Plan										Command. Identifies unit location, the location of subordinate leaders and other personel as required. It also includes, Succession of command (i.e. if the squad leader becomes a casualty, then who will assume command of the squad; normally, 1st fire team leader, or main effort leader, then 2nd fire team leader, 3rd fire team leader, or supporting effort leaders, etc.). This heirarchy is essential for maintaining control of the unit and its drive toward mission accomplishment. A menu box should list all available humans and machines under the team that are visible to UTACC and allow for the prioritization of each. This can be a separate optional field needing human input that may be different from the roles that were selected for the humans under the "define roles of human and robot within teaming environemtne capability".
	Signal Plan										Signal Plan includes: Prearranged signals. Passwords and countersigns. Radio call signs, frequencies, and radio procedures. Emergency signals. Pyrotechnics. Restrictions on the use of communications. The frequency range that the robots operate on must be adjustable allowing it meet FCC regulations in CONUS and OCONUS. Menu box allowing for selection of restrictions on communication should be made available if operating under EM contested conditions.
	Retrasmit Plan										The UXVs possess the ability to extend the human elements transmission range by serving as intermediary retransmit nodes in a communications link. With this capabilty the UTACC team could potentially push further away from higher headquarters where communication links were once more difficult to maintain or required additional communication gear. The UXV's ability to receive and retransmit data should not interfere with their ability to communicate within the team and may necessitate an auxillary communication channel.
	Pre-mission Comm Check										Ensure communication links have up to date encryption and that the timing is shared. The timing window is the duration of time that the link will remain on a given frequency when freq hopping mode is in effect. The encryption will specific the order of frequencies used during freq hop. Thought on design: make compatible with current PRC communication suite and DAGGER encryption fill devices.

The OPD requirements listed in Figure 17 focus more on system requirements than on interface design. The fields of information are of use to the system in identifying and tracking friendly units; understanding where to go and what to do when electronically cut off from the team; prioritize who to take commands from; and when and how long to communicate. These two final paragraphs, the “A” and “C” paragraphs of the 5PO, complete the *Begin Planning* phase of the BAMCIS work flow.

B. ARRANGE RECONNAISSANCE IA TABLES

The second phase of the Troop Leading Steps work flow is the A in BAMCIS, arrange reconnaissance. The tasks associated with UTACC in this phase involve conducting initial mapping in order to orient the team to the area of operations and selecting emphasis areas.

1. Arrange Reconnaissance: Conduct Initial Mapping to Orient

Conducting initial mapping to orient involves the following subtasks: depart friendly lines; scan area between origin and objective for geographic features; scan objective area for basic geography; build a map; notify when near the completion of mapping; monitor system health; review initial map highlight areas for further refinement; and query external joint assets. Due to the size of the Arrange for Reconnaissance IA Table, it was broken down into four smaller IA tables for the ease of presenting it in this thesis.

a. Initial Mapping: Depart and Scan between Origin and Objective

Figure 18 depicts the task decomposition for the first two of six subtasks under the task for conduct initial mapping to orient; it also provides the OPD requirements for achieving them.

Figure 18. Arrange Reconnaissance: Initial Mapping: Depart and Scan between Origin and Objective

			Option 1			Option 2			Option 3			
Tasks	Subtask	Capacity	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Conduct Initial Mapping to Orient	Depart Friendly Lines	Resolve Airspace										Humans can deconflict air space and it would also be helpful to build in this capability into the UAS. (need them to not bump into each other and be able to take off and get into scan pattern. amazon suggests. Establishing fly zones from UAVs have ceilings (400ft with 100ft buffer above) and No Fly Areas for restricted air space. These normal altitude parameters should be default set and used in the design of lenses and imagine devices but should allow for field modifications, especially the NFAs. Examples of NFAs include active landing zones and drop zones, holding areas for helicopters, and other air control measures where aircraft are designated to operate in. The ability for military air craft to share the same airspace would require ability for drone to detect manned (and unmanned aircraft) and deconflict in an EM contested environment. Also, should be able to tap into gun target lines and surface danger zones to deconflict altitude with artillery and mortar trajectories. This can be accomplished by drone ability to remotely access command battle tracking systems.(initial map is a geographic map that is captured by the UAS only.)
	Scan Area Between Origin and Objective for Geo Features	Understan Size of Area to Scan Between Origin and Objective										the human must determine and communicate the size (overlap of scans) and location of the area to be scanned. the human can streamline efficiency and timeliness of the system by constraining the initial mapping of the area. This requires an interface that allows the human to input military grids (MGRS). A scaled grid square of varying dimensions can then by applied to a military map projection display for the human to "shave off unnecessary scan areas." it will also be necessary for the human to identify starting point through use of grids and or other points of interest through grids or highlighting on the display. It may also be possible that no additional information is available outside of starting grid and objective grid and that the human operator would need to determine only size of box to scan. (point clouds vs three model vs overhead imagery)
		Plan for How to Scan the Area										the UAS will be able to plan it's route for scanning to meet the objects defined above. The human may be able to help focus/ narrow down the area. By using intuition to trim the map down or use of joint assets to trim. with the above mission parameters defined for the scan the robot should determine how to efficiently map the area. This will take into account overlapping scan patterns so that it can correlate data from one scan to data in the next (line up the images). registration issue. (use of map is for collision avoidance. What has been searched and found and what hasn't? Who is using it and why? If robots, then what format and is it useful for them? If for the human, same question?

The OPD requirements for the resolving airspace capacity involve free and safe flight of the UAS from takeoff to landing. The OPD requirements associated with understanding the size of the area to scan between origin and objective established a box shaped operating area for the UAS with the origin in one corner and the objective in the corner diagonally opposite. The OPD requirements for the task, plan how to scan the area, identify information that the system must provide to the Marines.

Figure 18 offers the first glimpse of true interdependence at work during the BAMCIS process. The pattern of colors that emerges from Figure 18 indicates that the Marine and machine are communicating with one another and are relying on one another to do some element of work that the other is incapable of conducting. The first row within Figure 18 shows that the UAS is capable of carrying out the given capacity. The second row depicts a hard constraint, i.e., a hard interdependence, where the human is required to perform a function. The third row shows that the UAS is capable of carrying on with planning after receiving human input. The OPD requirements for this row provide the Marine a visual aid to understand what the UAS scan path and time of flight will look like, based off how that Marine shapes the scan area (the information exchange from the second row of Figure 18).

Figure 18 offers insight regarding where UTACC should spend time and resources during the development cycle and where it should not. The hard interdependencies of row two in Figure 18 should be avoided from an automation perspective. The Marines have the ability to quickly and effortlessly provide a capability that the system is incapable of mastering, rather than getting bogged down trying to marginally provide an automated capability that the Marine is available for and would prefer to have control of in the first place. Development should, however, focus on rows one and three of Figure 18. The issues with rows one and three can be fixed during development. These issues lie in the translation of the [already present] information that is necessary for Marines and machines to make their decisions. The human must determine and prioritize what is important to scan. That ability is greatly enhanced if the system can visually display a correlated time of flight and scan path as the Marine plays with the parameters of the scan box. These requirements introduce opportunities for the Marines and robots to share information for the first time during the BAMCIS process. This theme will emerge several times over throughout the remainder of the IA Tables' analysis.

b. Initial Mapping: Scan Objective and Build Map

The second set of subtasks under the task of conduct initial mapping to orient are: scan objective area for basic geography and build the map. Each subtask has multiple capacities: execute initial mapping protocol; generating actionable information; transmitting map information; identifying between urban and wooded areas; and identifying masked areas. The OPD requirements for these capacities are shown in Figure 19.

Figure 19. Arrange Reconnaissance: Initial Mapping: Scan Objective and Build Map

			Option 1			Option 2			Option 3			
Task	Subtask	Capacity	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Conduct Initial Mapping to Orient	Scan Objective Area for Basic Geo	Execute Initial Mapping Protocol										UxS based on input above self determines mapping protocol. Human might be able to help out if other constraints like culture/civilian constraints or stealth etc. assumed that Marines could map the area but the time is assumed to take too long.
		Generate Actionable Info										Generate actionable information. assume CMU collaborative mapping capability extends to all UTACC UxS's.
	Build Map	Transmit Map Info										Systems can use each other to find most efficient way of transmitting data back to the Marines.
		Identify Between Urban and Wooded										Identify between urban and wooded
		Identify Masked Areas										UxS's need to share with each other what they have not covered and help each other to cover. there is a capability of the UAS and UGS from their collaborative map that allow them to see areas they weren't able to map effectively without the other. And ability to communicate to team.

The OPD requirements for Figure 19 are centered on improving the UAS in the performance of its duties and not in translating information from Marine to machine or vice versa. These requirements aim to improve sensor quality and processing on board the system and are only limited to the scope of current technology. This is much simpler to address compared with translating information exchanges between Marines and machines. Similar to the Begin Planning IA Tables, where the human was doing the majority of the work, here the UAS is required to take on the lion's share of the work.

c. *Initial Mapping: Notify when Complete and Monitor System Health*

The final two subtasks of the task conduct initial mapping to orient are: notify when near completion of mapping and monitor system health. Each has one capacity and the OPD requirements associated with achieving them are listed in Figure 20.

Figure 20. Arrange Reconnaissance: Initial Mapping: Notify when Complete and Monitor System Health

			Option 1			Option 2			Option 3			
Tasks	Subtask	Capacity	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Conduct Initial Mapping to Orient	Notify When Near Completion of Mapping	Alert Marine When Planning Threshold Hit										Marines in the initial planning will have to create initial threshold and communicate it to the UxS's and UxS's will need to communicate back to Marines when threshold hit. Need a visual indicator (progress bar) of how much has been mapped and a separate correlation to the mission. ie. 30% mapped and will be 20min behind timeline.
	Monitor System Health	Understand When to Return for Maintenance/ Refueling										UxS's need to monitor state with relation to task and health RTB when required. Marines have the option to monitor their state and then direct UxS's to RTB. Assume UAV sends mapping data in real time back to UTACC manager. Assume health monitoring display.

The OPD requirements for Figure 20 follow a similar trend to Figure 19. Their aim is to enhance the UAS in sensing and processing. A few minor interface designs are suggested to keep the Marines cognizant of the UAS' status while conducting the initial mapping.

2. Arrange Reconnaissance: Select Emphasis Area(s)

The Arrange Reconnaissance IA Table's final task is select emphasis area(s). It is broken down into two subtasks: review initial map highlight areas for further refinement and query external / joint assets. The former subtask has one capacity and the latter has two. Figure 21 depicts these and the OPD requirements.

Figure 21. Arrange Reconnaissance: Select Emphasis Area(s)

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Select Emphasis Area(s)	Review Initial Map Highlight Areas for Further Refinement (angle, resolution, sensor, camera direction, etc.)	Identify Potential Danger Areas, Routes, LZs, Water Features, etc.										Human input is required. Interface converts input into algorithms so that whatever box the human draws over the map is understood as area to be covered. The reason why it is being recovered needs to be conveyed so that the robot knows what it will be doing differently on the future pass. (perspective, hi resolution, IR, Camera, heat.
	Query External/ Joint Assets/ COP	Request Relevant Joint Mapping Information										Human input is required through the UTACC CMU.
		Incorporate Joint Mapping Info into System										Human needs to be able to translate join assets into a machine understandable format. Assumption is that machine is not able to take inputs from other systems currently. is info from other systems in a form that the robot can use? If the new info is required for future mission of robot but the robot can't read it, then it needs to self map the area anyway. Can the new info, which is in a human form, be relayed to the robot some how so that it is useable/actionable?

The OPD requirements in Figure 21 shift back to a Marine focus. This handoff from machine to Marine demonstrates that the machine has satisfied the Marine's immediate need for information and is allowing the Marine to process that information. This task completes the Arrange Reconnaissance IA Table and the second step in BAMCIS.

C. MAKE RECONNAISSANCE IA TABLES

The third phase of the Troop Leading Steps work flow is the M in BAMIS: make reconnaissance. The tasks associated with UTACC in this phase involve conducting detailed mapping, and creating the modified combined obstacle overlay (MCOO). The make reconnaissance phase is partitioned into two separate IA Tables.

1. Make Reconnaissance: Return, Scan, Alert, Notify, and Monitor

The first task of the Make Reconnaissance IA Table, conduct detailed mapping, is broken down into five subtasks: return to selected emphasis area(s); scan selected emphasis area(s); alert team to relevant map information; notify team when near completion of mapping; and monitor system health. Figure 22 depicts each subtask, its capacities, and associated OPD requirements.

Figure 22. Make Reconnaissance: Return, Scan, Alert, Notify, and Monitor

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Conduct Detailed Mapping	Return to Selected Emphasis Area(s)	Prioritize List of Areas Needing Refinement										Prioritize list of areas needing refinement
		Resolve Airspace										Humans can deconflict air space and it would also be helpful to build in this capability into the UAS.
	Scan Selected Emphasis Area(s)	Execute Detailed Mapping Protocol										UxS based on input above self determines mapping protocol. Assumed that Marines could map the area but the time is assumed to take too long.
		Build Detailed Map Collaboratively										Built between UxS's. assume CMU collaborative mapping capability extends to all UTACC UxS's.
	Alert Team to Relevant Map Info	Transmit Map Information										Systems can use each other to find most efficient way of transmitting data.
	Notify When Near Completion of Mapping	Alert Marine When Planning Threshold Hit										Marines in the initial planning will have to create initial threshold and communicate it to the UxS's and UxS's will need to talk back to Marines when threshold hit.
	Monitor System Health	Understand When to Return for Maintenance/ Refueling										UxS's need to monitor state with relation to task and health RTB when required. Marines have the option to monitor their state and then direct UxS's to RTB. Assume UAV sends mapping data in real time back to UTACC manager. Assume health monitoring display.

Due to the similarities in the two tasks, the OPD requirements in Figure 22 are similar to those under conduct initial mapping. However, the completion of the detailed mapping is necessary for the output of the next task, which is a critical planning factor for missions.

2. Make Reconnaissance: MCOO

The second task of the Make Reconnaissance IA Table is the generation of a MCOO. MCOOs are broken down into specific overlays, the generation of which specifies the subtasks of this task: vegetation; surface drainage; other effects; combined obstacles; mobility corridors; and avenue of approach. Sub-overlays can often be broken down further into specific features, each of which constitutes a single capacity. This breakdown and the corresponding OPD requirements are shown in Figure 23.

Figure 23. Make Reconnaissance: MCOO

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
MCOO (modified combined obstacle overlay)	Depict Vegetation	Depict Type of Vegetation										Depict tree spacing, trunk diameter, soil types, and conditions that affect mobility.
	Depict Surface Drainage	Depict Water Sources										Depict width, depth, velocity, bank slope, height, and potential flood zones
	Depict All Other Effects	Depict Surface Configuration										Depict elevation, slopes that affect mobility, line of sight for equipment usage.
		Depict Obstacles										Natural and manmade obstacles.
		Transportation Systems										Depict bridge classifications and road characteristics such as curve radius, slopes, and width.
	Depict Combined Obstacles	Depict Severely Restricted Terrain										>45% slope. Hinders or slows movement in combat formations unless some effort made to enhance mobility. Double hashed lines used to indicate area. Depicted in green if on land, blue if a body of water.
		Depict Restricted Terrain										31-45% slope. Hinders movement to some degree; little effort is needed to enhance movement, but units cannot move at preferred speeds or formations. Depicted in green if on land, blue if a body of water.
		Depict Unrestricted Terrain										0-30% slope. Indicates terrain free of constraints to movement; no need to enhance mobility so no delineation is required.
	Depict Mobility Corridors and Avenues of Approach											The mobility corridor itself is relatively free of obstacles and allows a force to capitalize on the principles of mass and speed. Identifying mobility corridors requires some knowledge of friendly and threat/adversary organizations and their preferred tactics. The best mobility corridors use unrestricted terrain that provide enough space for a force to move in its preferred doctrinal formations while avoiding major obstacles. Mobility corridors can follow, for example, the direction of roads, trails, rivers, streams, ridgelines, etc.. An avenue of approach (AA) is an air or ground route of an attacking force of a given size leading to its objective or to key terrain in its path. The identification of AAs is important because all Courses of Action (COAs) that involve maneuver depend on available AAs.

The OPD requirements from Figure 23 describe the capacities, or in this case, the features of each of the individual overlays that contribute to the greater MCOO. Iconography for the interface design is incorporated where appropriate. The color coding indicates that the UxVs are gathering data collaboratively. The two systems are heavily coordinating activities at this stage of BAMCIS, and it is important that their information exchanges be designed seamlessly. The Marines are able to rest and refit during this portion of BAMCIS with only minimal requirements to monitor the system’s health and the collection of data through the building of the MCOO user interface. The MCOO task is the final step in the Make Reconnaissance IA Table and the third step in BAMCIS.

D. COMPLETE THE PLAN

The fourth phase of the Troop Leading Steps work flow is the C in BAMCIS: complete the plan. The tasks associated with UTACC in this phase involve developing, refining, selecting, and submitting mission profiles to higher headquarters for approval and assignment of supporting / joint assets. The complete the plan phase of BAMCIS is partitioned into seven separate IA Tables.

1. Complete the Plan: Develop Mission Profiles

Six of the seven IA Tables correspond to six different subtasks. The subtasks relate to the different teaming options available for completion of the mission: Marines only; UAVs only; UGVs only; Marines and UAVs only; Marines and UGVs only; and Marines, UAVs, and UGVs all working together.

a. Develop Mission Profiles: Marine Only Profile

The Marine only profile has four capacities: identify conditions that keep UxVs from partnering further, providing a route from assembly area to objective, providing imagery of key terrain features along the route and of the objective area, and providing an estimated time line. So even though the UxVs may not be partnering fully during this profile option, UTACC is still providing valuable information to the Marine only team through the interface.

Figure 24. Develop Mission Profiles: Marine Only Profile

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Develop Mission Profiles	Develop Marine Only Mission	Identify Conditions that Keep UxVs from Partnering Further										Interface should show Marine if timeline can be met by UxV. Interface should identify weather conditions and terrain that prohibit UxV use. Human input is required to determine if mission security/stealth is impacted by UxV.
		Provide Route from Assembly Area to Objective										UxV should determine route for team. Human input should be allowed (in the following select profile stage, refinement to the mission profile requires the human to adjust or have UTACC rework the profile.
		Provide Imagery of Key Terrain Features Along Route and of Objective Area										The UxVs should provide imagery of features (intersections, river crossings, objective areas, rally points, check points, etc.) Human selection of these areas would improve efficiency and reduce the number unnecessary files shared.
		Provide Estimated Time Line										The UxVs should calculate timeline based off of distance, terrain, and speed of march (speed of march should be calculated using standard fighting load weight). If carrying weight is different from standard, human should have ability to adjust.

The OPD requirements of Figure 24 specify inputs that both the Marine and the machine need to provide and step through what that communication might look like. The collaboration on the interface is achieved in the form of recommended routes, imagery, video feeds, and adjustable time tables. The color coding schemes displayed in Figure 24 are all indicative of soft interdependency requirements, which would serve as excellent areas for the UTACC design team to focus efforts and resources. All of the capacities are things which the system can do with slightly less than one hundred percent reliability or where assistance is necessary.

b. Develop Mission Profiles: UAV Only Profile

The UAV only profile has four capacities: identify conditions that keep UGV and Marines from partnering further; provide areas requiring surveillance; provide the time on station per UAV; and provide the time on station with a rotation of UAVs. Even though the UGVs and Marines may not be partnering fully during this profile option, they are still providing valuable information to the UAV only team through the interface. Figure 25 depicts the capacities and associated OPD requirements.

Figure 25. Develop Mission Profiles: UAV Only Profile

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Develop Mission Profiles	Develop UAV Only Mission	Identify Conditions that Keep UGV and Marines from Partnering Further										Interface should show Marine if timeline can be met by UxV. Interface should identify weather conditions and terrain that prohibit UxV use. Human input is required to determine if mission security/stealth is impacted by UxV.
		Provide Area Requiring Surveillance										If UAV only mission is necessary, Human input is required for designating area to survey.
		Provide Time on Station per UAV										If UAV only mission is necessary, interface should show time on station before UAV must leave to refuel.
		Provide Time on Station with Rotation of UAVs										If UAV only mission is necessary, interface should show time on station allowed with both UAVs rotating in and out based off of refueling and transit times. Human in put not possible.

The OPD requirements for Figure 25 are different than those of the Marine only and UGV only profiles despite having similar capacities. This may also be evident from the drastically different color coding schemes. The UAV only color coding scheme indicates that there are some hard interdependency requirements which should be avoided or minimized during development. Requirements are limited largely to interface designs that allow the human to monitor system health.

c. Develop Mission Profiles: UGV Only Profile

As with the UAV only profile, the UGV only profile has four capacities: identify conditions that keep UAV and Marines from partnering further; provide areas requiring surveillance; provide the time on station per UAV; and provide the time on station with a rotation of UAVs. Even though the UAVs and Marines may not be partnering fully during this profile option, they are still providing valuable information to the UGV only team through the interface. Figure 26 depicts these capacities and associated OPD requirements.

Figure 26. Develop Mission Profiles: UGV Only Profile

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Develop Mission Profiles	Develop UGV Only Mission	Identify Conditions that Keep UAV and Marines from Partnering Further										Interface should show Marine if timeline can be met by UxV. Interface should identify weather conditions and terrain that prohibit UxV use. Human input is required to determine if mission security/stealth is impacted by UxV.
		Provide Area Requiring Surveillance										In the first scenario, the UAV can identify danger areas (choke points, historical IED strike/find points or small arms fire points, and potential ambush sites) and mark those as areas needing surveillance. In the second scenario, the UGV can identify and mark similar areas but with less efficiency and reliability than the UAV and would require assistance from UAV. In both scenarios, human input would be needed to approve these areas and prioritize them if they would otherwise overwhelm the system. Human intuition may also identify areas not picked up by the UxVs. The interface should allow for these interactions and provide the human visual cueing to areas needing surveillance.
		Provide Time on Station per UGV										If UGV only mission is necessary, interface should show time on station before UGV must leave to refuel.
		Provide Time on Station with Rotation of UGVs										If UGV only mission is necessary, interface should show time on station allowed with both UGVs rotating in and out based off of refueling and transit times. Human input not possible.

The OPD requirements listed in Figure 26 have a pattern reminiscent of that shown in the UAV only profile. However, the soft interdependence in the second row of the UGV only profile may prove to be more favorable for UTACC system developers as a focus area. The last two rows of the UGV only profile indicate the same hard interdependencies, which should be avoided from a development perspective.

d. *Develop Mission Profiles: Marine and UAV Profile*

The Marine and UAV profile has four capacities: identify conditions that keep UGVs from partnering further, determine if route from assembly area to objective will be different for Marines and UAVs, identify additional tasks for the UAVs to conduct in route to the objective, and identify additional tasks for the UAV to conduct at the objective. Even though the UGVs may not be partnering fully during this profile option, they are still providing valuable information to the team through the interface. Figure 27 depicts these capacities and associated OPD requirements.

Figure 27. Develop Mission Profiles: Marine and UAV Profile

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Develop Mission Profiles	Develop Marine & UAV Mission	Identify Conditions that Keep UGV from Partnering Further										Interface should show Marine if time line can be met by UxV. Interface should identify weather conditions and terrain that prohibit UxV use. Human input is required to determine if mission security/stealth is impacted by UxV. The UAV may identify terrain or time/space reasons why the UGV cannot participate. The UGV may have collected data during recon on why it cannot participate that is not obvious to the UAV. Human oversight will be needed.
		Determine if Route from Assembly Area to Objective will be Different for Marines and UAV										The UAVs may need to take a completely different route to the objective based off of air space deconfliction or for security reason. Interface should recommend optimal routes for UxVs and Marines. It should allow humans to dictate whether route should be shared or different. This input should be optional. If separate routes are needed. The routes should be visible to the Marines and an alert should indicate what was addressed.
		Identify Additional Tasks for the UAV to Conduct in route to Objective if Applicable										UAV may be used to maintain security and control of an area like an extract site on the exfiltration from the objective. It may be used to recon a bridge for structural integrity or a route clear of obstacles. The interface should allow the user to highlight the area(s) and indicate the length of time to remain in position and task to preform. If this step is omitted the UAV will travel to the objective.
		Identify Additional Tasks for the UAV to Conduct at the Objective if Applicable										It may be used to track individuals fleeing the objective on foot or vehicle. The interface should allow the user to highlight the area(s) and indicate the length of time to remain in position and task to preform. If this step is omitted the UAV will loiter at the objective and wait further tasking.

Now that the profiles contain two nonhomogeneous entities, the OPD requirements from Figure 27 have grown slightly more complicated. Some of the reason for the increased convolution is due to the tactical situation and the variable mindsets of Marines. For instance, a Marine, under certain circumstances, may wish to have the UxVs move with the human team and, in other circumstances, may not want to be even remotely close to the system. The requirements of Figure 27 that offer potential for developers, again, lie in the second row, as the color coding indicates a soft interdependency. The human is locked into providing input in the bottom two rows of Figure 27, indicated by the hard interdependency color codes.

e. Develop Mission Profiles: Marine and UGV Profile

The Marine and UGV profile has four capacities: identify conditions that keep UAV from partnering further, determine if route from assembly area to objective will be different for Marines and UGVs, identify additional tasks for the UGVs to conduct in route to objective, and identify additional tasks for the UGV to conduct at the objective. Even though the UAVs may not be partnering fully during this profile option, they are still providing valuable information to the team through the interface. Figure 28 depicts these capacities and associated OPD requirements.

Figure 28. Develop Mission Profiles: Marine and UGV Profile

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Develop Mission Profiles	Develop Marine & UGV Mission	Identify Conditions that Keep UAV from Partnering Further										Interface should show Marine if time line can be met by UxV. Interface should identify weather conditions and terrain that prohibit UxV use. Human input is required to determine if mission security/stealth is impacted by UxV.
		Determine if Route from Assembly Area to Objective will be Different for Marines and UGV										The UAV may have information about the route's traffic ability that affects the UGV and would improve reliability of the UGV route. The Marine may want the UGV to travel to the objective along a different route because the route they are using is un-trafficable by the UGV. Interface should recommend optimal routes for UxVs and Marines. It should allow humans to dictate whether route should be shared or different. Optional input..
		Identify Additional Tasks for the UGV to Conduct in route to Objective if Applicable										UGV may be used to maintain security and control of an area like an extract site or to clear a route of possible IEDs, it may be used to recon a bridge for structural integrity or a route clear of obstacles. The interface should allow the user to highlight the area and indicate the length of time to remain in position and task.
		Identify Additional Tasks for the UGV to Conduct at the Objective if Applicable										UGV may be used to maintain security and control of an area like an extract site or to clear a route of possible IEDs, it may be used to recon a bridge for structural integrity or a route clear of obstacles. The interface should allow the user to highlight the area and indicate the length of time to remain in position and the task to preform.

A color coding pattern emerges again, where the second row offers the soft interdependencies, ripe for design and development, followed by hard interdependencies. The OPD requirements in Figure 28 revolve around the same concept of offering different routes for Marines and UxVs; however, the fact that the UGVs are more restricted by terrain than UAVs offers additional challenges. Similarly, these restraints limit the tasks that the UGV can conduct in route to or at the objective. Examples are listed in the IA Table.

f. Develop Mission Profile: Marine, UAV, UGV Profile

The Marine, UAV, UGV profile is the most complex of the teaming options. It also has four capacities: determine if route from assembly area to objective will be different for Marine, UGV, and UAV; identify additional tasks for the UGV to conduct in route to objective; identify additional tasks for the UAV to conduct in route to the objective; and identify tasks for the UAV to conduct at the objective. Figure 29 depicts these capacities and associated OPD requirements.

Figure 29. Develop Mission Profile: Marine, UAV, UGV Profile

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Develop Mission Profiles	Develop Marine, UAV, UGV Mission	Determine if Route from Assembly Area to Objective will be Different for Marines, UGV, and UAV										The UAV may have information about the route's traffic ability that affects the UGV and would improve reliability of the UGV route. The UGV will not have information that affects the UAV route. The Marine may want the UxVs to travel to the objective along a different route because the route they are using is un-trafficable by the UGV or the UAV will give away the Marines position. Interface should recommend optimal routes for UxVs and Marines. It should allow humans to dictate whether route should be shared or different. This input should be optional.
		Identify Additional Tasks for the UGV to Conduct in route to Objective if Applicable										UGV may be used to maintain security and control of an area like an extract site or to clear a route of possible IEDs, it may be used to recon a bridge for structural integrity or a route clear of obstacles. The interface should allow the user to highlight the area and indicate the length of time to remain in position and task to preform.
		Identify Additional Tasks for the UAV to Conduct in route to Objective if Applicable										UAV may be used to maintain security and control of an area like an extract site on the exfiltration from the objective. It may be used to recon a bridge for structural integrity or a route clear of obstacles. The interface should allow the user to highlight the area(s) and indicate the length of time to remain in position and task to preform. If this step is omitted the UAV will travel to the objective.
		Identify Additional Tasks for the UGV to Conduct at the Objective if Applicable										UGV may be used to maintain security and control of an area like an extract site or to clear a route of possible IEDs, it may be used to recon a bridge for structural integrity or a route clear of obstacles. The interface should allow the user to highlight the area and indicate the length of time to remain in position and the task to preform.

The OPD requirements for Figure 29 revolve around the Marine's decision as to whether or not to travel together. The three bottom rows of Figure 29 are hard interdependencies that require the Marine to prepare additional tasks for the team members. The interface design offers minor possibilities for interdependence despite these hard interdependencies.

2. Complete the Plan: Refine, Select, and Submit Profile(s)

The final table of the seven Complete the Plan IA Tables corresponds to three tasks. These tasks do not require much decomposition, and the relationships of the agents are simple. It is, however, important to list the tasks, as they are steps requiring documentation in the work flow. Figure 30 depicts these tasks and their OPD requirements.

Figure 30. Complete the Plan: Refine, Select, and Submit Profile(s)

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Refine Mission Profile(s)	Select Profile(s) Needing Refinement											Each options should be presented to the human in the form of a route(s) and timeline. The human may prefer to one or a few profiles based on their analysis of the situation, however, they may not be satisfied with some of the details of that particular profile.
	Select Areas Needing Refinement											Once the Marine has selected the profile(s) that need refinement, they need to open up the profile and select an area to avoid or an alternate route to take, or designate different UxV tasks.
	Conduct Refinement (Selection of Alternate Route, Require which Agents Utilize Routes)											The interface should rework the profiles and present them as options to the Marine to accept or select for additional refinement. This process is iterative until the Marine selects the mission profile to be completed.
Select Mission Profile												Once satisfied with the profiles, the Marine selects the one that meets their desired end state.
Submit to HHQ for Approval and Assignment of Supporting/ Joint Assets												The interface should allow the human to send the mission profile to HHQ. A prompt should indicate when and if Joint assets are available.

The OPD requirements in Figure 30 highlight how information should be presented to the Marines. As the Marines review the profiles that were prepared, it is important that profiles support a few interaction mechanisms, which are listed in the table. Following the refinement task, the Marine then selects the profile to be executed and submits it up to the next higher unit. This task closes out the C in BAMCIS.

E. ISSUE THE ORDER IA TABLE

The fifth phase of the Troop Leading Steps work flow is the I in BAMCIS: issue the order. There is only one task for this phase, which is able to be captured in a single IA Table. The lone task is further broken down into the following subtasks: issue the order and conduct three dimensional rehearsals. Figure 31 captures this task and its OPD requirements.

Figure 31. Issue the Order

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Issue Order and Conduct Rehearsal	Issue Order	5 Paragraph Order Issued to Team										The human team leaders is issuing the completed 5 Paragraph order or Frago to his team. The interface should present him with the order that has been refined throughout the BAMCIS process and which the team leader approved prior to the Issue stage. There is nothing the UxVs can contribute with during this time, therefore as the Marine team is coming off their rest and refit time, the UxVs should be using their available time to refuel.
	Conduct 3D Rehearsal											A rehearsal of the mission profile that is to be conducted is necessary for all Marines to demonstrate an understanding of the plan and work through any potential areas of friction. The interface should visually depict the movement of the team from the assembly area through to actions on the objective. If a retrograde or raid mission is planned where a planned withdrawal is planned for, it should also be included during in visual rehearsal. Additional physical rehearsals of intricate or critical mission elements (such as actions on the objective) may also need to be conducted. This portion of the rehearsals is optional and time and situation dependent. Furthermore, the mission leader should have the option of incorporating the UxVs into portions of the walk through. Any down time should be spent recharging the UxVs. Mission should not commence until the UxVs are fully charged/refueled.

The OPD requirements for Figure 31 reflect that the system, which has performed the lion's share of the work throughout BAMCIS up until now, is entering into its down cycle, whereas the Marines are coming off of theirs. Now that sufficient data has been collected and analyzed, the planning process nears its end, and Marines prepare to execute their mission. The 5PO is issued to ensure that all members are aware of the plan. This phase of BAMCIS is completed after rehearsals are conducted with both a 3D display via the interface and physical walk-throughs.

F. SUPERVISE ACTIVITIES

The final phase of the Troop Leading Steps work flow is the S in BAMCIS: supervise activities. This phase possesses five IA Tables consisting of six tasks, including: sensor posture, select formation, the task module, maintenance alerts, maintain common operational picture (COP), and tactical alerts and cueing. The work compiled by Rice et al. (2015) was instrumental in shaping this task decomposition as well as the OPD requirements for this phase. A separate column was added to the right of these IA Tables, labeled after the Rice et al. (2015) Task Analysis Worksheets (TAW). Also, the capacity column of the tables identifies terms that Rice et al. (2015) developed. An abridged version of the Rice et al. (2015) description for these terms is listed under the TAW column.

a. Supervise Activities: Sensor Posture

The first task, with its own IA Table, is sensor posture. This task is distilled down into four different postures, each associated with its own capacity: defensive, neutral, offensive, and degraded. The descriptions of these postures and their OPD requirements are provided in Figure 32.

Figure 32. Supervise Activities: Sensor Posture

			Option 1			Option 2			Option 3				
Tasks	Subtask	Capacity	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements	Rice et al. (2015) Task Analysis Worksheet Quotes
Sensor Posture	Select Sensor Posture	Defensive Sensor Posture										UAVs should deconflict sensor scan sectors based on the situation. The default deconfliction plan could be as simple as North/South. This may need to change depending on the situation. The terrain may require much more time to scan one sector than the other, requiring something other than a 50/50 breakup of scan sectors. Sensors should provide on demand updates to CTP regarding enemy location and identification information. Defensive Sensor Posture is assumed to be default in absence of Marine input. The UGS cannot assist the UAS with its sensor posture. The UAS may be able to assist the UGS with its sensor posture. The system should provide: 1. Alert updates 2. 3D map update that makes route unpassable for UTACC ground systems. 3. High quality coordinates. 4. On demand Sensor data to team member(s) display. 5.On demand location ids.	The Defensive Sensor Posture (DSP) is primarily used when the small tactical unit leader requires maximum sensor coverage of a friendly position such as in the defense or when moving in a highly uncertain and/or hostile environment. The Defensive Sensor Posture should be considered the "default" sensor posture as it requires no additional information from the team leader to execute. .
		Neutral Sensor Posture											The neutral sensor posture (NSP) means that the UAVs maintain one sensor on the small tactical unit, while the other sensor stays focused on the objective.
		Offensive Sensor Posture											The Offensive Sensor Posture (OSP) is primarily used when actions on the objective are imminent and the team leader wants maximum coverage and intelligence regarding the objective
		Degraded Sensor Posture											The degraded sensor postures are used when UTACC has one UAS available for employment. UTACC must either use that UAS for over watch of the small tactical unit, or for ISR of the objective area. UTACC should default to DDSP and keep providing ISR of the friendlies unless directed by the leader to transition.

The OPD requirements for Figure 32 delineate a set of outputs that the system should provide once the Marine picks a sensor posture. The postures are defined in the TAW column. As color coded in Figure 32, the UxVs will be able to choose a posture for themselves, requiring Marine approval after the fact.

b. Supervise Activities: Select Formation

The next task under the S in BAMCIS is select formation. This task has been decomposed into machine only formations, and combined formations. The capacities represent those formations which Rice et al. (2015) determined from scratch or in the case of a combined formation, adapted from Marine Corps doctrinal publications. In either event, the description of the capacity is listed in the TAW column. Along with the OPD requirements, these capacities and descriptions are listed in Figure 33.

Figure 33. Supervise Activities: Select Formations

			Option 1			Option 2			Option 3				
Tasks	Subtask	Capacity	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements	Rice et al. (2015) Task Analysis Worksheet Quotes
Select Form-ation	Machine only formation	Balanced										UTACC takes inputs and produces a route to follow to the designated location. The Small Unit Leader can approve the route, or provides additional inputs and UTACC produces a revised new route. The interface now has: (1) a refined 3D map, (2) alert updates in the form of Enemy, Navigation, UTACC status, etc., (3) on demand sensor data to Small Tactical Unit member display (4) on demand location and ids for Enemy, Small Tactical Unit members and UTACC components.	Air, Ground Carriers and UGVs maintain maximum dispersion while maintaining stealth and speed of movement as mission dictates.
		Forward Focused											Both UGVs will be deployed to front of Carriers maintaining uniform distance to the carriers providing increased sensor input to UTACC.
		Rear Focused											Both UGVs will be deployed to rear of Carriers maintaining uniform distance to the carriers providing increased sensor input to UTACC
		Side Focused											UGVs will be deployed to the left or right side of Carriers and move parallel to the carriers providing increased sensor input to UTACC.
	Combined Formation	Column										Leader gives hand signal for wedge and direction. Leader is able to adjust positions. Air Carrier establishes initial position between Rifeman and Leader. Ground Carrier establishes initial position between Automatic Riflemen and Assistant Automatic Riflemen. Interface provides on demand location and ids.	Human Component- Basic fire team formation that Permits rapid, controlled movement, favors fire and maneuver to the flanks, but is vulnerable to fire from the front and provides the least amount of fire to the front
		Echelon										Leader gives hand signal for echelon and direction. Leader is able to adjust initial positions. Air Carrier initial position between Rifeman and Leader. Ground Carrier initial position between Automatic Riflemen and Assistant Automatic Riflemen. Interface provides on demand location and ids.	Human Component- Basic fire team formation that provides heavy firepower to front and echeloned flank, and is used to protect an open or exposed flank. [
		Wedge										Leader gives hand signal for wedge and direction. Leader adjusts initial positions. Air Carrier initial position in the center of formation. Ground Carrier initial position 50m to the rear. Interface provides on demand location ids.	Human Component- Basic formation that permits good control, provides all-round security, provides flexibility and allows adequate fire in all directions.
		Skirmish										Leader gives hand signal for echelon and direction. Leader is able to adjust positions.. Air Carrier initial position behind Rifeman and even with Leader. Ground Carrier initial position behind Automatic Riflemen and even with Assistant Automatic Riflemen. Interface provides on demand location ids.	Human Component- Basic formation that provides maximum firepower to the front, and is used when the location and strength of the enemy are known, during the assault, mopping up, and crossing short open areas.

The OPD requirements for Figure 33 provide a list of outputs that the system should have displayed on the interface, as well as further guidance on machine team member location within combined formations. The color coding depicts soft interdependencies. The robots are capable of moving into position within the formation themselves but could be assisted from either of the other parties and thus increase reliability.

c. *Supervise Activities: Task Module*

The task decomposed in the following IA Table is the actual task module, where tasks are executed within the work flow. This work is broken down into the following stages: departing friendly lines; insertion and infiltration; actions on the objective; and re-entry of friendly lines. The capacities and OPD requirements are listed in Figure 34.

Figure 34. Supervise Activities: Task Module

			Option 1			Option 2			Option 3			
Tasks	**Subtask**	**Capacity**	**UAS**	**UGS**	**M**	**UGS**	**UAS**	**M**	**M**	**UAS**	**UGS**	**OPD requirements**
Task Module	Execute Task	Depart Friendly Lines										UxVs have left friendly lines for the third time potentially now. Another round of internal system checks should be automatically performed to ensure they have all required information and resources (i.e. Fuel, Air Control Measures, Fire Support Control Measures, Tactical Control Measures).
		Insertion and Infiltration										Team will proceed from insertion point/ friendly lines to objective rally point in formation chosen by Leader. Because infiltration is likely conducted during periods of darkness and through somewhat restrictive terrain, UGVs must be capable of operating in these conditions. Ground sensors can be utilized to assist team members with navigation and force protection during movement. Air sensors can be utilized for force protection, as well as surveillance of the ORP and the objective. The noise signature of the UxVs is an important consideration regarding insertion and infiltration. At the ORP, the UxVs may be staged there temporarily or utilized to conduct a hasty recon of the objective in order to very that conditions on the objective have not changed since departing friendly lines. If continuous coverage of the objective has been provided by the UxVs and the team leader decides not to conduct a hasty recon of the objective, the ORP may still be utilized to stage unnecessary gear or pause before entering the objective. Interface should be updating the patrol report with as mission unfolds.
		Conduct Actions on the Objective										The UxVs can be utilized for a variety of purposes regarding actions on the objective. For the reconnaissance mission, sensors can enable increased standoff for the small infantry unit reducing the risk of compromising the location of the ORP. This could be particularly helpful in sparse terrain where cover is difficult to find. The UAVs, in addition to providing eyes on the objective, would be useful as a communications relay to report PIRs to the operations center.
		Conduct Re-entry of Friendly Lines										Simple procedure intended to prevent fratricide. The UGVs could potentially be used as the lead elements for re-entry in case of mistaken identity. Implementing some form of transponder on the UxVs could allow returning units to be *interrogated* prior to re-entry as an additional measure to prevent fratricide.

The OPD requirements for Figure 34 are derived from soft interdependences as indicated with the color coding. The requirements offer simple procedures, design mechanisms, a variety of purposes, and even limited cyber considerations.

d. Supervise Activities: Maintenance Alerts

The third task under the S in BAMCIS is maintenance alerts and is broken down into the following four capacities: fully, partially, and non-mission capable sensor statuses (FMC, PMC, NMC respectively), and monitoring fuel levels. These statuses and their descriptions—as developed by Rice et al. (2015)—and the OPD requirements are listed in Figure 35.

Figure 35. Supervise Activities: Maintenance Alerts

Tasks	Subtask	Capacity	Option 1			Option 2			Option 3			OPD requirements	Rice et al. (2015) Task Analysis Worksheet Quotes
			UAS	UGS	M	UGS	UAS	M	M	UAS	UGS		
Maint Alerts	Provide Alert Message to the Team When System Health Degrades	Identify When Sensors Health is Fully-Mission Capable (FMC).										There are situations when a component could be rendered NMC prior to having an opportunity to report this information (hits an IED and instantly is destroyed). The other components need to realize that this component is now missing (components routinely "ping" each other?). The NMC alert would then be communicated to the team by one of the other UTACC components. Color coded alerts (FMC, PMC, NMC) to user interface regarding sub-system health of UTACC components. When a sub-system is found to have failed or is degraded, the component must reference some sort of matrix regarding which alert to trigger. For example, the loss of the laser used for 3d mapping could render the component NMC if the assigned task is to return with a 3d map. If the assigned task is wide area surveillance, this would be a PMC loss. There are certain losses that will be universal (task independent). For example, the UAV always needs an engine, rotor blades, fuel, and a flight control system to operate.	FMC: When testing multiple sub-components within UTACC, minor faults and degrades will likely be discovered which do not affect the performance of UTACC in support of a task. These failed components belong in the "FMC" category and need not be communicated to anyone. The results of the failed tests should simply be saved for download next time the component returns for maintenance.
		Identify When Sensors Health is Partially-Mission Capable (PMC).											PMC: PMC failures are failures which result in UTACC operating in a degraded mode. For example, the loss of the 3d mapping capability while it still retains the ability to perform standard surveillance. This failure would need to be communicated, via a CUE (no human input required) to the team leader through the primary user interface device. Since these failures are not as serious as NMC failures, recommend color coding these alerts (orange for PMC, red for NMC).
		Identify When Sensors Health is Non-Mission Capable (NMC).											NMC: Failures which restrict a UTACC component from operating and/or performing the assigned mission. This could be either the loss of all sensors, or the critical failure of a major sub-component such as the engine, flight control system, etc. NMC failures must be presented immediately to the team leader, via an ALERT, through the user interface system (recommend red color).
		Monitor Fuel Levels and Advise When Fuel Threshold Met.										The UxVs must gauge their own fuel states and be able to report it in terms of time left on station.	While not specifically a maintenance issue, fuel states will be an additionally "component health" issue that could be presented using the preceding metric. A PMC alert could be issued when a component has 15 (or 20, or 30) minutes time on station before needing to return for fuel. A NMC alert would then be issued as the component checks off station, notifying the team that this component is no longer available.

The OPD requirements for Figure 35 identify that the mission must go on even in the face of degraded sensors. Providing the ability to assure Marines of the status of the sensors will reinforce their confidence in what the systems are telling them and in the systems as a whole. The color coding indicates that these capacities are hard interdependencies that rely on the system to be able to self-diagnose and report.

e. Supervise Activities: Maintain COP and Tactical Alerts / Cueing

The final Supervise Activities IA Table has two tasks associated with it: maintain common operational picture (COP), and tactical alerts and cueing. The former is broken down into sending imagery and data back to the COP and leaders; the latter is broken down in the following two capacities: recognizing tactical alert scenarios and recognizing cueing scenarios. These capacities and their OPD requirements are listed in Figure 36.

Figure 36. Supervise Activities: Maintain COP and Tactical Alerts / Cueing

			Option 1			Option 2			Option 3			
Tasks	Subtasks	Capacities	UAS	UGS	M	UGS	UAS	M	M	UAS	UGS	OPD requirements
Maintain COP	Send Imagery and Data Back to COP and to Leaders											They may be positioned during this portion of the mission to extend the communication lines, where the UxVs serve as intermediate relay nodes in the communication link between the objective back to a HHQ or adjacently operating unit that would otherwise experience degraded or no communication links.
Tactical Alerts and Cueing	Provide Alert Message to Team When Critical Tactical Events Occur (Team Response Required)	Recognize Tactical Alert Scenario										The UxVs should always notify the team of critical tactical events, including: when in the vicinity of checkpoints and other important grids, when a high value target or be on the look out was spotted, direction and distance of enemy contact, etc.
	Provide Cues to Team When Less Than Critical Tactical Events Occur (Team Response Optional)	Recognize Cueing Scenario										The Team Leader may also want the UxVs to notify him of additional events like approaching traffic, or potential hot spots along the route where possible IEDs may be emplaced, etc.

The OPD requirements in Figure 36 are formed on hard interdependencies between the system components and the Marines. This means that the UxVs are able to collaborate and assist one another; however, very little room exists for direct Marine feedback. In other words, the Marines will be reliant on the systems to notify them in the event that a specified scenario is tripped into action. These tasks complete the S in BAMCIS, and with it, they terminate the BAMCIS process.

G. CHAPTER SUMMARY AND CONCLUSIONS

This chapter presented the results of melding the Mission Planning and Execution Model with the Coactive Design Model. BAMCIS was the flow of work, or framework, around which the Mission Planning and Execution Model was structured. Inserting that framework into the IA Tables, which are the design and analysis tool of Coactive Design, allowed the author to develop multiple observability, predictability, and directability requirements. These requirements provided Marine-specific insight to the UTACC developers and highlighted development focus areas that were based on soft and hard interdependencies. These suggested refinement areas offer the potential for the greatest return on time and resources spent while developing capacities and highlighting areas where the Marine is well suited to support the machines. This is often a support relationship that is overlooked in developing smart systems.

1. UTACC Focus Areas: The Five Feedback Categories

Information is vital to making decisions and the process of gathering and disseminating information to a team composed of humans and machines, which each collect and require in different forms, is inherently difficult. When conducting the traditional task decomposition process associated with the IA Tables, it became apparent that the information exchanges between the Marines and machines could be sorted into the following five feedback categories:

- Scoping the Area of Interest
- Scoping the Area of Uncertainty
- Platform Capability
- Sensor Capabilities
- Time Constraints

The first two categories are human judgment calls. In other words, the human needs to provide feedback to the system in order for it to then be able to make decisions and conduct work. These two categories require the ability to identify the important areas and the ability to prioritize how the system approaches work. Within the last three categories the system provides feedback to the humans, in order for the Marines to be able to make decisions. It is suggested that feedback loops be designed that allow the Marine to adjust the parameters of the system and gauge the effectiveness of the machines while they are collecting information. The direction of the feedback loops, whether it is flowing to or from the Marine or the machine, is of little importance as long as there is interplay between both agents. This is the essence of interdependence.

2. Author's Marine Perspective Applied to the UTACC Focus Areas

From the author's perspective as a Marine infantryman, effectively incorporating these feedback loops into the final system should appear intuitive and be as streamlined as possible. The following illustration guided the development of the IA Tables in this chapter:

a. Scoping the Area of Interest

When scoping the area of interest, the machine is in need of the starting location of the team and the objective. With these two points an operating box (op box) can be established where the machines will scan and conduct work. The size of this op box may be too large to efficiently scan or there may be areas within the box that are of no interest to the Marine Corps. A visual, electronic map with adjustable parameters and a tool that correlates the remaining op box area with the sensor, as well as platform capabilities are perceived to be of great use to UTACC. If Marines are able to graphically see this correlation as they are adjusting the parameters, they would be able to more accurately and efficiently shave the areas requiring scanning. Simply put, moving a boundary a few millimeters left or right on a tablet might have the same perceived impact to the Marine, whereas to the machine that is required to conduct the scan of the area, it means another three hours and two passes overhead with a refueling session. This could be time that the team does not possess. This correlation should be presented with a digital clock depicting the time required to scan and an icon with a perimeter related to the range of the machine's sensors. This would be a good example of predictability.

b. Scoping the Area of Uncertainty

Scoping the area of uncertainty can be accomplished in a similar manner. Having just scoped the area of interest, the Marine is left with a filter over their op box that meets their time line. Over the same filter, the Marine should then be permitted the ability to prioritize the areas most in need of scanning. Perhaps the area within a few hundred meters of the team's starting position is of little worry and would, then, be prioritized low. If the scanning time window shrinks, as planning timelines often do, then the hope would be that the highest priority areas would be scanned.

c. Platform and Sensor Capabilities and Time Constraints

Other platform and sensor capabilities not discussed in the preceding feedback loop discussions may have a substantial impact on the usability of the system. The interface should, at a minimum periodically, if not continuously, update with machine location. This information should be displayed on the filters mentioned earlier so that Marines can gauge efficiency and effectiveness. This information exchange would allow them to make adjustments in route. The Marines need to be able to maintain awareness about what the machines are doing and how they are performing. To facilitate this end, a system health graphic is necessary for the display, visible on the interface. However, as with all of these requirements, simplicity is desired. A battery icon with a percentage of remaining battery life should be displayed for each machine in the field. A check engine light that, when scrolled over, displays the exact malfunction, or warning, is desirable, as well. The warning should initially drop down from the periphery of the interface and remain for a few seconds, allowing the Marines the opportunity to read it, before disappearing and then leave behind just the check engine light.

This scenario was developed with a few of what the author deems as the most important system requirements. The focus of this scenario was the second step in the BAMCIS process, arrange for reconnaissance. A comprehensive BAMCIS process scenario would become too convoluted and was not attempted. For an inclusive understanding of the requirements obtained from this thesis, refer to the individual IA Tables.

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V. SUMMARIZING RESULTS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This thesis has two main impact areas. The first analyzes the merits of whether the Coactive Design Process is useful to MCWL in developing the UTACC system of systems. The second is using Coactive Design to produce a list of design requirements that captured complicated concepts like coordination, collaboration, and cooperation. The author focused on interface features and behaviors as the mechanisms for capturing those requirements. The third mechanism suggested by Johnson (2014), not taken into account here, was control algorithms and is better left to the UTACC software and systems engineers. The author's personal experience as a Marine Corps infantry officer was also taken into account, not only when shaping these design requirements but also in providing perspective to the UTACC team and stakeholders.

A. SUMMARY OF RESULTS

As Johnson (2014) stated "Coactive Design breaks with traditional human-machine design approaches by focusing on effective management of interdependencies verses focusing on autonomy." It has a foundation in systems engineering and as an iterative design and development method is well suited to meeting the demands of a future military system where requirements will change throughout the development life cycle.

1. General Comments

Communication is key to any relationship. The processes for how information is shared so that decisions can be made vary widely from relationship to relationship and only increase in complexity with the addition of individuals or agents. Within the construct of human-machine teaming, humans and machines speak in different languages and require different pieces of information, often times in formats unusable by the other agent. The UTACC system's interface is the tool by which the human is able to communicate with the robots and vice versa. It is in this medium that information is pushed and pulled by both human and machine components for planning, rehearsing, and executing a mission. The UTACC specific IA Tables address many elements that need to be incorporated when developing the interface in order to maintain the interdependencies between the Marines and machines.

The Marine Corps Troop Leading Steps, BAMCIS, were used to structure the work flows analyzed under the Coactive Design lens. By using this concept, of which all Marines are familiar, the SoS is able to integrate more seamlessly into the ways Marines already gather information and act. This reduces the amount of system learning required of organizations that typically accompanies adoption of new technology. Additionally, it accelerates the time with which Marines will begin to experiment with the technology and use it in creative and beneficial ways other than those in which it was originally intended. Therefore, creating a system that complements the existing Marine Corps framework is critical.

2. Benefits of Coactively Designing UTACC

Coactive Design offers three distinct benefits to UTACC as it seeks to grow in size and scope over a timeline that is appealing to Department of Defense (DOD) acquisition officials. These benefits are (1) DOD familiarity, (2) a resilient system, and (3) focusing efforts in a time and resource constrained development environment. They are elaborated on below.

a. Capitalizing on DOD Familiarity with the Coactive Design Approach

Coactive Design is an emergent human-machine system design method that gained the attention of the Department of Defense (DOD) during two recent demonstrations. The first demonstration was the 2013 Defense Advanced Research Projects Agency's (DARPA) Virtual Robotics Challenge (VRC). There, Coactive Design author, Dr. Matthew Johnson, working with the Florida Institute of Human Machine Cognition (IHMC) earned a commanding first place out of 126 potential competitors. The second demonstration was the 2015 DARPA Robotics Challenge (DRC), where IHMC earned top honors and second place out of the 24 competing teams. Of note, both IHMC and the first place winner of the 2015 competition earned the same point score during the competition. Task completion time was chosen as the tie breaker, and the winning team's creativity in working around the bipedal constraints of the competition during a few of the prescribed challenges allowed it to shave enough time to pull into the lead. IHMC's ability to complete this task as a bipedal robot demonstrated a level of mastery of a very complicated robotic function that was lacking in the winning teams prototype. For these reasons, Coactive Design is, at the time of this writing, being explored by DARPA for an experimental, enterprise wide, Pilot's Assistant Program. Further investing in Coactive Design for use with UTACC would capitalize on the DOD familiarity with it, and would align with the Marine Corps' Expeditionary Force 21 (EF21) strategic initiative to remain on the cutting edge of technology.

b. Flexibility over Brittleness

The second advantage offered by Coactive Design to UTACC is flexibility. UTACC is a SoS that will need to operate in a complex environment where uncertainty will be highly prevalent. Being able to perform the same task in many different ways is what IA Tables help identify, rather than building the system to work under circumstances that may be hard to attain in real life. Furthermore, when a system is designed with too much dependence on the robot to operate autonomously, and without any alternative pathways for the work to be completed, the system is said to be brittle. Coactive Design targets this brittleness by considering multiple pathways through a task that take advantage of the unique capabilities that both humans and machines bring to the team. As a result, when one alternative fails, the mission may continue on.

As Dr. Johnson (2014) often stated, "In robotics, if you do not plan to fail, you are failing to plan." When placing robots into a teaming environment, designers must consider uncertainty and build in the capabilities to respond to unexpected events. This requirement is addressed by designing resilience into the system, which brings about the third advantage offered by coactively designing UTACC.

c. Developing Efficiencies in Design and Development

The Coactive Design approach to developing UTACC provided an excellent cost-benefit study of development choices during IHMC's preparation for the DRC (Johnson, 2014). IHMC had one and a half years to develop their humanoid robot for the demanding and wide ranging challenges encountered in the DRC. With a limited budget, small time window, and host of issues designed to instill a sense of uncertainty over the challenges, IHMC needed a means of focusing their effort on high reward development issues. UTACC would benefit in a similar fashion as it is pressed to develop a resilient teaming focused SoS on budget despite a host of software engineering timelines.

As indicated in the UTACC IA tables, UTACC engineers should seek to avoid developing highly "autonomous" recognition capabilities where a simple cue to a Marine equipped with a superior sense of situational awareness could quickly approve or dismiss a potential threat or target. Just as the IHMC team saved a lot of time and money by not investing in complex perception and planning, so too could UTACC (Johnson, 2014). Instead UTACC should focus resources on enabling the human to be an effective teammate, much as Johnson (2014) did during the DRC. This thesis has argued that the best ways of enhancing the Marine's effectiveness is with the presentation of information collected by the team, through (1) the user interface and (2) designing for multiple alternatives in task completion. Eliminating the 100 percent solution (e.g., the ends of the autonomy spectrum: full autonomy or full teleoperation) eliminates the hardest problems. The Coactive Design method engineers systems that exploit synergy between systems and humans—which is what teaming is all about.

B. SUGGESTED UTACC FOCUS AREAS BASED ON COACTIVE DESIGN

When conducting traditional task decomposition processes associated with the IA Tables it became apparent that the information exchanges between the Marines and machines could be sorted in the following five feedback categories.

- Scoping the Area of Interest
- Scoping the Area of Uncertainty
- Platform Capability
- Sensor Capabilities
- Time Constraints

The first two categories are human judgment calls. In other words the human needs to provide feedback to the system in order for it to then be able to make decisions and conduct work. These two categories require the ability to identify the important areas and the ability to prioritize how the system approaches work. Within the last three categories the system provides feedback to the humans in order for them to be able to make decisions. It is suggested that feedback loops be designed that allow the human to adjust the parameters of the system and gauge the effectiveness of the machines while they are collecting information. The direction of the feedback loops, whether it is flowing to or from the Marine or the machine, is of little importance, as long as there is interplay between both agents. This is the essence of interdependence.

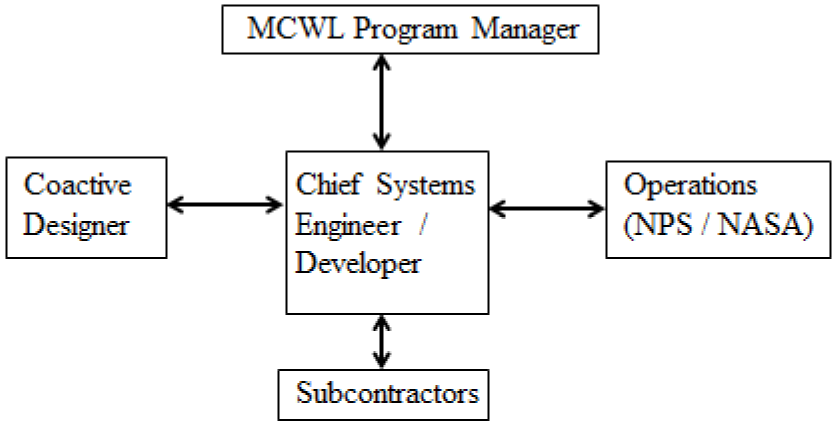
C. RECOMMENDATIONS FOR FUTURE RESEARCH

This work was only the initial step in developing a coactively designed UTACC. It has analyzed the merits of pursuing this specific design approach and recommended that it be adopted for the duration of the program. Furthermore, this thesis has made recommendations on initial system requirements and bridged much of the previous concept development work with the tool that achieves these requirements, the IA Table. As an iterative design process, truly capitalizing on Coactive Design requires investing in it over the long term, which may be achieved through the following:

1. System Engineering in the Program Organizational Structure

The first recommendation to sustaining the momentum brought about by this thesis is to incorporate a coactive designer into the existing UTACC program's organizational structure. Figure 37 is a recommended organizational chart that graphically depicts the administrative and operational relationships such a Coactive Designer would need in order to ensure proper utilization.

Figure 37. Coactive Designer in the Program Organizational Structure



As with all software design projects, the designer and developer should be in constant conversation. Such conversation is not characterized by one role being subjugated to the other. Rather, mutual respect for the insights and contributions of each respective position must be acknowledged. It is of critical importance that the conversations and interactions of these two positions be physically joined to the greatest extent possible. This is not limited to merely working in the same building, although that would appear a bare minimum. The designer and developer should occupy the same work space, be entwined in every phase of the project from concept development, requirement generation, programming, testing, and evaluation. Doing so will only enhance the system's flexibility, benefitting the overall project resiliency.

2. Maintain Momentum by Overlapping Turnover among Designers

As with any iterative design, the true insights come about after the designer and developer exchange perspectives. It was observed by the author that after holding a team meeting, where the Coactive Design results were shared with the normally physically disparate project team members that design potentials were not only realized but were actually improved upon. Given the physical isolation of the project's team members, at least one other gathering of the minds should be held where the author could conduct a proper turnover of knowledge and experience with his replacement and more aptly guarantee a smooth transition among designers. This turnover would greatly reduce the amount of time it would take to get a new designer familiar with previous work conducted and could alleviate many of the issues that would arise should that new designer not have background working in the Marine Corps infantry.

3. Designing beyond the Demonstrations

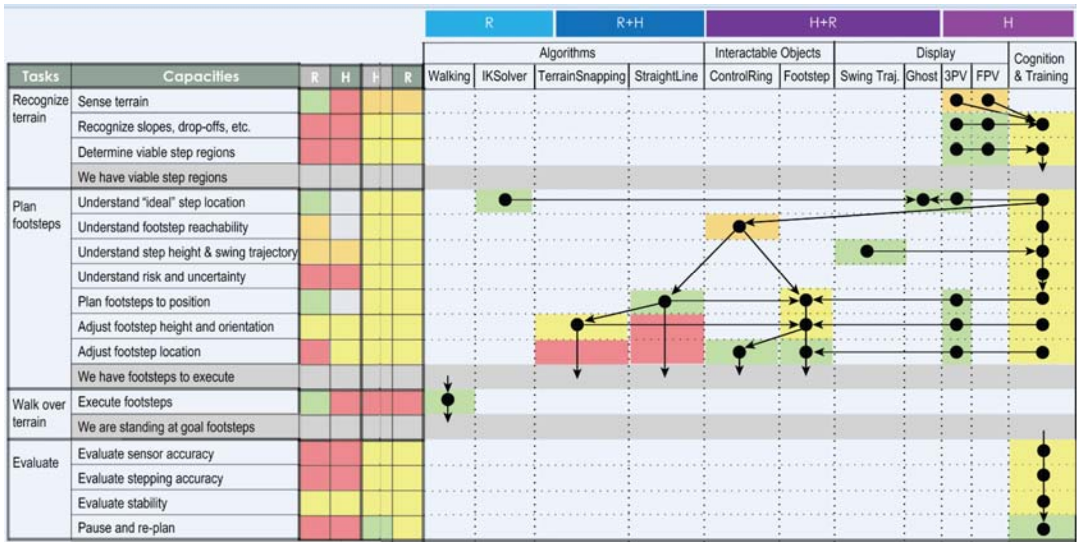
This thesis has made recommendations for where UTACC should focus its limited efforts within the many design requirements identified in the UTACC IA tables. Achieving all of them will require that multiple drafts of IA tables be tied to experimentation and the prescribed evaluation of change processes with accompanying feedback loops into the identification processes.

The set of scoped recommendations served the purpose of meeting a 2016 UTACC demonstration, which extended an earlier proof of concept demonstration. Under tight time and resource constraints, the UTACC project team used the UTACC IA Tables to focus their efforts. The team selected only a few of the requirements identified. When moving beyond this second iteration demo, it is recommended that future Coactive Design selection and implementation periods be implemented. During these periods the team should take a look at incorporating and expanding the remaining requirements found within the IA Tables of this thesis and explore new areas as UTACC's scope grows.

4. Building a Final Resilient System

Alternative teaming options are a part of this thesis. The UTACC Coactive Design IA Tables specify three generic teaming options for every subtask that is specified. The next step, beyond the scope of this thesis, is to depict the multiple pathways through a given alternative. Figure 38 graphically depicts what this would look like.

Figure 38. The Pathways through an IA Table's Alternative Teaming Options



Sources: Johnson, M., Shrewsbury, B., Bertrand, S., Calvert, D., Wu, T., Duran, D., Stephen, D., Mertins, N., Carff, J., Rifenburgh, W., Smith, J., Schmidt-Wetekam, C., Faconti, D., Graber-Tilton, A., Eyssette, N., Meier, T., Kalkov, I., Craig, T., Payton, N., McCrory, S., Wiedebach, G., Layton, B., Neuhaus, P., & Pratt, J. (in press). Team IHMC's lessons learned from the DARPA robotics challenge: Finding data in the rubble. *Journal of Field Robotics*.

Figure 38 is an expanded IA Table taken from IHMC's lessons learned from the DRC. It adds several extra steps to the analysis of teaming alternatives (represented in the right half of the figure). A detailed description of this process is beyond the scope of this thesis. The important takeaways include: the columns identifying which component will perform work; the sub-columns to the components that specify the design requirement, which controls the capacity; the ability to list multiple components as able to perform work; the ability (through color coding) to depict the range of a components' ability to perform work; and a means of physically and logically tracing multiple paths through the workflow to completion of the task.

Tracing the alternative pathways through a task allows developers to more accurately identify where the soft interdependencies lie, and thus where development efforts should be focused. Furthermore, mapping out these multiple pathways, provides the Marine-machine team with alternative ways of recognizing and handling the unexpected. The teamwork infrastructure's flexibility is supported with a multitude of interdependent relationships. Naturally, these alternatives should be a part of the training regime designed for UTACC.

5. Three Selling Points: Dull, Dangerous, and Dirty

When deciding on future requirements to pursue, or when creating new ones, there are three points that will further help to direct efforts.

- What task is difficult to do?
- What is dull or boring to do?
- Is the system annoying or difficult to use?

When designing H-M systems, the goal is to bring the human to the things that they should be focusing on. The machine should be mapped to the human and not the other way around. This is easily stated but often becomes difficult to put into practice. UTACC aims to reduce the cognitive load of the human with respect to controlling the system but does not seek to eliminate the cognitive load entirely. The system requirements provided in this thesis focus on keeping the greater cognitive or judgment calls with the human so that they are not devoting all of their cognitive abilities to staring down a soda straw or completing basic mechanistic manipulation. The goal is not to remove the human operator from the equation but to reduce difficulty, remove dullness, and refocus towards accelerating, when necessary, the decision loop.

6. Levels of Information

The concept of maintaining a common operational picture (COP) where information from UTACC not only exists and can be passed within the Marine-machine team but integrates into the situational awareness of war fighters at all levels is appealing. This was a future research concept listed in the Rice et al. (2015) thesis as well. It merits re-mentioning for its relevance with big data issues, deciphering which data elements get passed, and to which level of command they ought to be delivered.

7. Number of Marines within the UTACC Team

This thesis' primary contribution, the IA Tables, simplified the number of agents analyzed down to one Marine, one unmanned aerial vehicle, and one unmanned ground vehicle. Marines do not operate as individuals in the field. Therefore, it is important to define whether UTACC is being designed to work with only one human within a unit or will all the members of a small tactical unit in order to effectively operate the SoS. If more than one human is the answer then further analysis is needed as to whether all of the Marines get the same interfaces, have the same abilities to push information to the machines, and make decisions about what to have the machines do. Perhaps the solution rests with a large, interactive tablet display for the unit leader with full administrative permissions and smaller interfaces that serve in a display only mode.

8. Emissions Protections

Due to the fact that the machines are sending large amounts of data and continuously communicating with the other members of the team and building a COP across all the levels of command, the potential of being detected by an adversary comes into play. It is theorized that some of the burden of reporting would be relieved due to this unsolicited communication, relieving the Marines of their need to pass position reports and elements of situation reports, as examples. However, it is not foreseen whether or not additional and unintentional reporting would be caused by this SoS. Further research is needed to develop electronic detection and protection procedures and their effects on reporting.

9. Authority among Machines

Just as other Marines must pick up the slack when an individual Marine is taken out of the fight in the middle of a mission, so too must the other machines pick up the slack when an individual machine goes down. The machines, especially when operating alone in the field, conducting remote mapping, would serve as easy targets. Additionally, they have to battle environmental and mechanical issues. Developing a rotating distribution of authority among the machines so that no head can be metaphorically chopped off is of critical importance. Similarly, by sharing a COP, the data gathered by one machine will not be lost should it go down.

10. Ethics of Robotics Use in Defining Military Missions

Developing robotic systems for use within the military brings to light many issues that are of little or no concern in the public sector. The incorporation of lethal and non-lethal weapons, targeting systems, and invasive surveillance technologies are potential progressions for any military robotic system. Singer's (2009) book, *Wired for War*, discussed how innovative technologies often develop unanticipated roles as users gain familiarity and confidence with their use. Brutzman et al. (2016) identified many key considerations and constraints that helped them define ethical military missions and their execution. As the UTACC system is developed, incorporating a framework similar to Brutzman's et al. (2016) could identify several of these potential missions.

11. Recommended UTACC Coactive Design Focus Areas

The UTACC design requirements presented in this thesis focus largely on graphical user interface design. Designing this series of interfaces with a BAMCIS backbone capitalizes on pre-existing Marine training and thought processes during the planning and execution phases of a mission. Incremental development of theses interfaces is suggested. It is essential that both the Marine-user and coactive designer are included during the multiple iterations of testing and evaluation. Figure 39 provides recommendations for the first increment of coactively designed interfaces.

Figure 39. First Increment Interface Elements

BAMCIS	Essential First Increment Coactively Designed Interface Elements
B	5 paragraph order (5PO) interface
A	Map (visually correlates adjustable op box parameters into time and space considerations)
M	Modified combined obstacle overlay (MCOO)
C	Mission profile options
I	3D rehearsals
S	Ability to direct the machines as the mission deviates from the plan (includes formations, immediate re-tasking, sensor postures, etc.)

The underlying goal of these interfaces is to translate information between the human and machine domains so that it may be of use to both of them. These design features make high level concepts like collaboration for human-machine teaming achievable under the UTACC construct.

D. CHAPTER CONCLUSION

Developing a resilient Marine-machine system capable of operating under various operational contexts and able to assist with the multitude of missions required of today's forces is no small task. The core issue surrounding the task relates to getting Marines and machines to work together. Coactive Design was built upon the concept of interdependence. Only after one understands the importance of how these interdependencies affect the teamwork infrastructure can one successfully build the bridge between the two agents.

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